JANUARY 1984 VOL. 6 NO. 1 $3.00 USA/$3.50 CANADA

THE JOURNAL OF INTELLIGENT MACHINES

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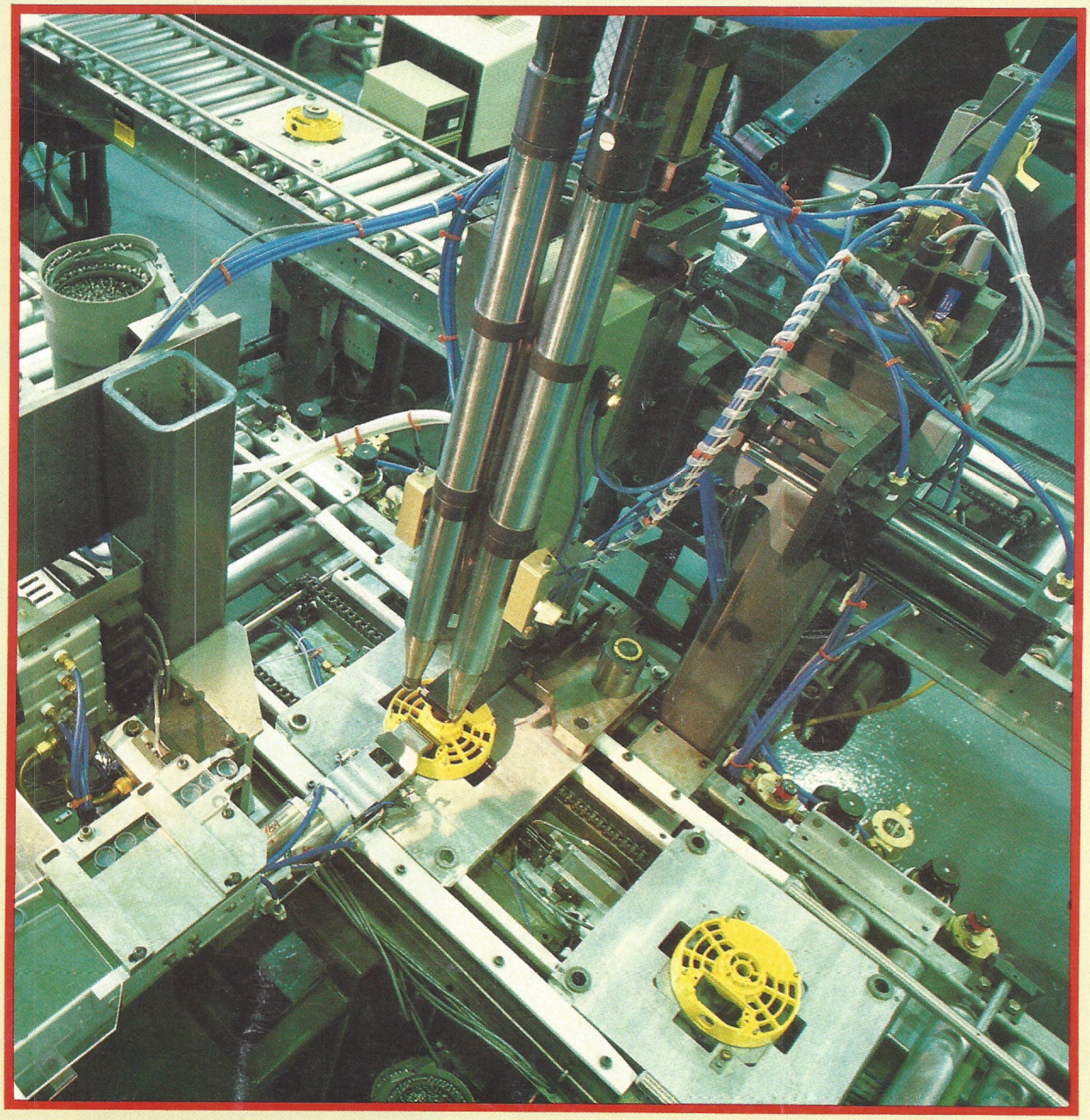

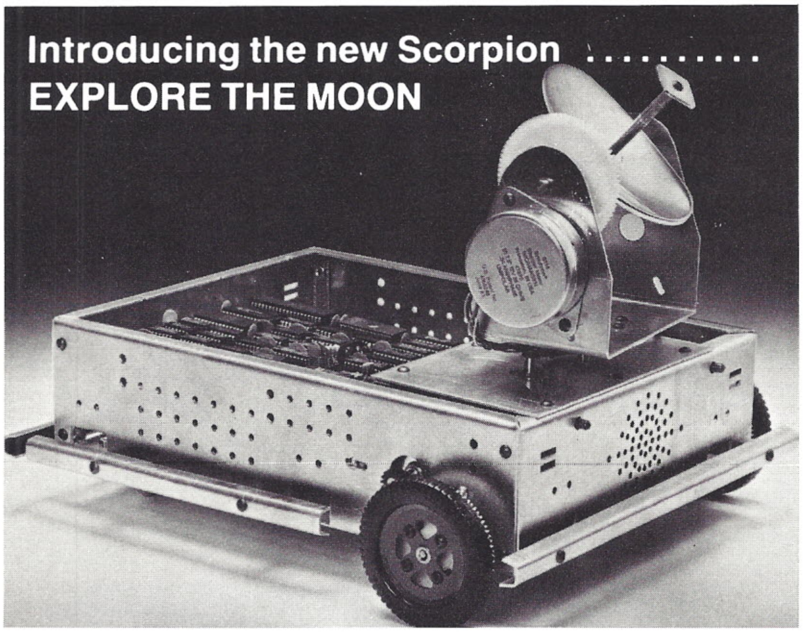

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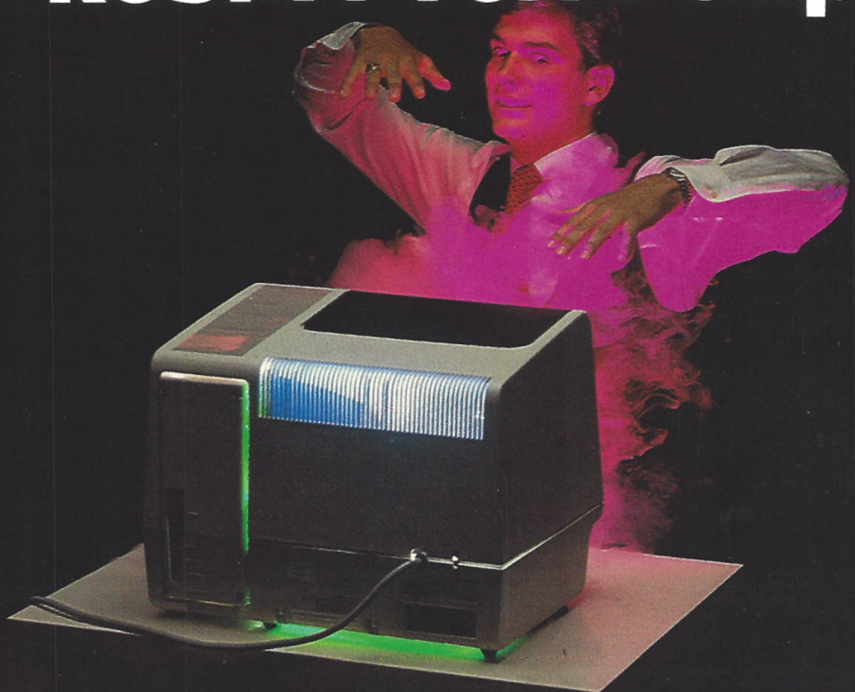

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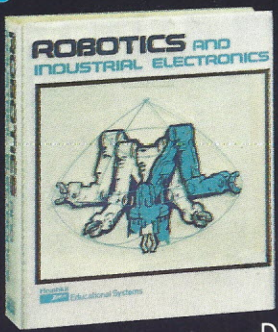

Remarkable though the robot is, its companion Robotics Education Course is an even more significant "first." It provides a thorough understanding of robot technologies, including robotics programming. Course features self-test unit reviews, experiments and final exam. Designed to be used with HERO 1, this 1200 page course is the most complete introduction to robotics available today.

HERO 1 is a computer on wheels. HERO 1 uses a 6808 microprocessor that controls 13 functions and sense boards. Its on-board processor can take it through complex maneuvers. The programming process is straightforward with provision for step-by-step debugging, enhancement and other corrections.

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The remarkable HERO 1 robot is in production now, ready for you. Buy assembled or build it from a kit. Kit price is $1500 and the assembled robot is $2500, FOB Benton Harbor, or through your nearest Heathkit Electronic Center.

For full information on HERO 1 call 800-253-0570 toll-free. (In Alaska, Hawaii and Michigan, call 616-982-3411.) We'll give you the address of the nearest Heathkit Electronic Center and send you a booklet that gives details about the robot, the content of this course, and other information.

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CIRCLE 19

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THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™

JANUARY 1984 VOL. 6 NO. 1

EDITORIAL

FEATURES

DEPARTMENTS

About the cover: An overview of the Westinghouse APAS Project. APAS provided significant insights into the use of robots for manufacturing small batches of products. The results of this research indicate that automation is feasible for batch manufacturing. Photo courtesy Westinghouse.

BPA Membership (SMA Division) Applied for, August 1983

The Need for Experimenters

RAYMOND GA COTE

Every technological advancement is characterized by two distinct groups: the commercial manufacturers attempting to profit from the new technology, and the experimenters and tinkerers who view it as a challenge to be met head-on.

An experimenter is not necessarily a backyard hobbyist. Many experimenters spend their days working with the very technology with which they experiment. Then they take their work home with them.

A field such as robotics that uses large, expensive equipment requires inexpensive learning tools with which people can experiment in order to spark creative thought. A person wishing to learn about stepper motors, microprocessor controllers, and feedback loops is more likely to purchase a small, $2,000 robot to connect to an already-owned personal computer than a $30,000 industrial-quality arm that requires an equally large and expensive control computer. The techniques used to program both machines are the same.

The knowledge required to produce functional robots encompasses several different fields of knowledge. The designer must understand the basic static and kinematic properties of mechanical structures; have a working knowledge of electronics and sensor operation; and understand the intricacies of real-time programming, which binds the operation of all parts into a smooth rhythm.

The experimenter maneuvering a newly-constructed mobile robot platform about the basement learns many important lessons:

- Control of mechanical devices
- Writing real-time software control routines
- Interaction with sensory information provided by bumpers, phototransistor eyes, ultrasonic ranging devices, and sound detectors

Industry benefits directly from experimenters in several ways. Today's experimenters are tomorrow's system designers. Before a technology can be used to its fullest potential, it must be well understood and accepted as just another tool for achieving a definite purpose. The experimentalists working on their own projects are developing a working understanding of robot technology. As a side effect, observers who see an interesting machine running about their neighbor's home will find it difficult to see that robot as a threatening device. As more of these "home" or "personal" robots are developed, the general public's potential fear of an unknown device will give way to a better understanding of a robot's use, and acceptance of the new technological advance.

The value of experimentation is summarized by the authors of *Super Armatron,* a student project to add computer control to a $30.00 plastic robot arm, "Although this robot arm can lift only 3 ounces, it provides an accurate microcomputer-controlled robot for experimentation. More importantly, the techniques used to construct and program Super Armatron can be directly applied to larger industrial robots." □

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Calendar

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Call For Papers. International Conference on Design and Applications of Industrial Robots. The University of North Carolina at Charlotte, Charlotte, NC 28223. Contact: Dr. Surendra Dwivedi at (704) 597-4190 or Mary A. McDaniel at (704) 597-2307. Suggested topics for the conference include: Representation Modeling; Sensors (tactile and vision); Manipulation; Locomotion; Intelligent Superstructure; and Applications. Send abstracts (100 words) to Dr. Surendra Dwivedi by January 31.

January 13-May 25. The Robot Exhibit: History, Fantasy, and Reality. American Craft Museum II at International Paper Plaza, 77 West 45th Street, New York, NY. Contact: Susan Harkavy, American Craft Museum II at International Paper Plaza, 77 West 45th Street, New York, NY 10036. (212) 397-0605.

The Robot Exhibit places the robot into social and historical context, tracing its nearly 5000-year development by displaying approximately 200 objects and major illustrations. Topics to be covered include: The History of Robots and Automatons; Interpretations of Robots; and Working Robots. Working robots, robot sculpture, toys, prints, photographs, slides, books, and video tapes will be lent by public and private collectors, artists, designers, inventors, and robot manufacturers.

MARCH

March 19-21. IEEE 1984 International Conference on Acoustics, Speech, and Signal Processing. Sheraton Harbor Island Hotel, San Diego, CA 92131. Contact: Sam S. Vilione, Interstate Electronics, 707 East Vermont Avenue, Anaheim, CA 92805. (714) 772-2811 X6327.

APRIL

April. Robot Olympics. California State College, San Bernardino, CA. Contact: Robot Olympics Committee, Computer Center, California State College, 5500 State College Parkway, San Bernardino, CA 92407.

The first Robot Olympics will be held on a weekend in April. Sponsored by various robot manufacturers, software developers, publishers, and dealers, the weekend will also sponsor introductory and application workshops. Competitions are designed for school grades kindergarten through 12.

April 23-26. Robotics and Remote Handling in Hostile Environments. Sheraton Hotel, Gatlinburg, TN. Contact: Norbert R. Grant at (615) 574-7123 or Howard W. Harvey at (615) 483-0228, or write to Technical Program Chairman, PO Box 326, Oak Ridge, TN 37830.

Plans are nearing completion for the 1984 Topical Meeting, "Robotics and Remote Handling in Hostile Environments" to be held at the Sheraton Hotel in Gatlinburg, TN, April 23-27, 1984. The meeting is sponsored by the American Nuclear Society's Remote Systems Technology Division (ANS/RSTD) and the Oak Ridge/Knoxville ANS Section. Session titles are: History of Manipulators and Robotics; Sensory Systems; Control Technology; Manipulator and Robot Applications; Remote Systems Applications in the Nuclear Industry—Fission; Remote System Applications in Other Hostile Environments; Technology Development and Remote Systems Technology Developments at ORNL.

MAY

May 7-11. 1984 Computer Aided Engineering and Manufacturing Seminars and Exhibition. North Carolina State University, McKimmon Center, Raleigh, NC 27605. Contact: Alice Strickland, NCSU, Division of Continuing Education, Box 5125, Raleigh, NC 27650. (919) 737-2261.

JUNE

June 4-7. Robots 8. Cobo Hall, Detroit, MI. Contact: Jeff Burnstein, Robotics Institute of America, PO Box 1366, Dearborn, MI 48121. (313) 271-0778.

Robots 8 is the eighth annual national show sponsored by RIA.

JULY

July 9-12. 1984 National Computer Conference. Las Vegas Convention Center, Las Vegas, NV. Contact: Ann-Marie Bartels, Las Vegas Convention Center, Las Vegas, NV. (702) 558-3613.

Enhancing Creativity is the theme of the twelfth annual NCC. The conference will focus on how the widespread availability of computing resources is altering the office, factory, and home.

NOVEMBER

November 27-29. Robots-West. Anaheim Convention Center, Anaheim, CA. Contact: Jeff Burnstein, Robot Institute of America, PO Box 1366, Dearborn, MI 48121. (313) 271-0778.

Robots-West is RIA's first regional show. It will feature exhibits by leading robot manufacturers and component suppliers. Approximately 6,000 visitors are expected to attend the three-day exposition and conference.

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- Five axes of movement so that it closely simulates full-scale industrial robots

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Circle 8

Sensory Perceptions

Mines Given Voice. Last September, Mimic, Inc. delivered a prototype voice warning system to the U.S. Department of the Interior's Bureau of Mines. The Vocal Output for Industrial Systems (VOIS^{TM}) system plays prerecorded messages from EPROM to alert vehicle operators to dangerous conditions. Messages can be activated either by hard-wired switches or an external computer connected via a parallel I/O port. The use of voice in control situations is designed to provide a maximum amount of information directly to vehicle operators without requiring them to shift their attention away from their work. For more information about VOIS, contact: Steve Thurston, Mimic, Inc., PO Box 921, Acton, MA 01720. (617) 263-2101.

Mobile Market. Two studies by SRI International reveal an existing market for nearly 100,000 mobile robots. Immediate uses include bomb disposal, private security robots, and firefighting hose carriers. The studies, commissioned by Odetics, Inc., also predict a market in many other industries including: mining, oil exploration and production, cargo handling and storage, commercial nuclear, medical, law enforcement, and utilities.

In addition to describing detailed needs in specific fields, SRI International's studies show the need for versatile mobile robots designed to perform specific tasks. The researchers believe "mobile robots will have a tremendous impact on industry. They have the potential of expanding man's work to inaccessible areas." Odetics, Inc., has already expanded the frontiers of mobile robots with their introduction last March of the Odex I Functionoid, their six-legged walking machine.

Naval Robots. A new laboratory dedicated to studying robotic applications for navy uses was formally opened on 21 October at the Naval Surface Weapons Center in White Oak—Silver Spring, Maryland. Vice Admiral Fowler, Jr., USN Commander of the Naval Sea Systems Command, stressed both the need to streamline the the construction and repair of Navy vessels and the need to closely support educational institutions working in the field.

The new laboratory's main thrust is the adaptation of existing robot technology to Navy applications. Robot system displays included a Cincinnati Milacron HT$_2{}^2{}_3$3, Odetics Odex I Functionoid, and a Seam Automated Welding System designed by Robotic Vision Systems. Also drawing crowds were Robart I and II. Designed and constructed by LCDR. Hobart Everett, the home-built Robart I was designed as a sentry robot and served as the subject of Hobart's thesis at the Naval Postgraduate School at Monterey, California. Robart II is being constructed under the auspices of the Naval Sea Systems Command as a mobile sensor test bed. The Robart I system was featured in the March/April 1982 *Robotics Age*.

Improving Imaging Transducers. Alta Technology, Inc., a manufacturer of transducers, is sponsoring a research associate at the National Bureau of Standards to improve the performance of electromechanical transducer arrays that employ piezoelectric polymers. Their arrays are useful in medical ultrasound imaging devices for diagnostics and in underwater acoustic cameras for object detection. Dr. Claude Massot of Alta Technology will work to develop a theory on non-propagating acoustical modes for transducer and experimental arrays to better understand performance with regard to sensitivity, angular dependence, and crosstalk.

Educational Tools. We continue to receive information from companies offering educational robotic devices. The latest is from Eshed Robotec, Ltd. in Tel Aviv, Israel. Eshed Robotec offers complete educational packages consisting of microcomputer support and robot arms. The study system comprises use of educational robots, projects with microcomputers, study material for teachers and students, audio visual aids, and laboratory and theoretical exercises. For more information contact Eshed Robotec, PO Box 28346, Tel Aviv, Israel.

Robotorium. Debbie Huglin operates the Robotorium, a tiny shop at 252 Mott Street in New York City. Debbie, who is a kinetic sculptor, sells a variety of mechanical gadgets ranging from wind-up animals to Rhino arms. Although few of the Robotorium's wares could be considered functional robots, they are all enjoyable. "There's no point in having a robot around the house if you can't go out and play with it, too," states Ms. Huglin.

New Journal. *Robotics and Computer-Integrated Manufacturing* is a quarterly publication which will begin publishing in January, 1984. Articles will cover topics such as control systems, languages, expert systems, processing bulk materials, machine tool error reduction, production scheduling, manufacturing systems modeling simulation, and high precision engineering and factory automation. Subscriptions are $45.00 per year. For more information contact: Pergamon Press, Inc., Maxwell House, Fairview Park, Elmsford, NY 10523.

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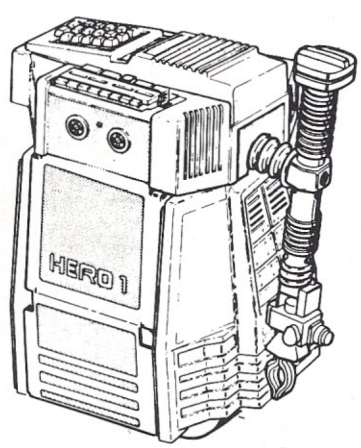

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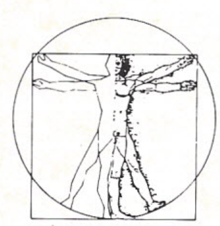

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Circle 9

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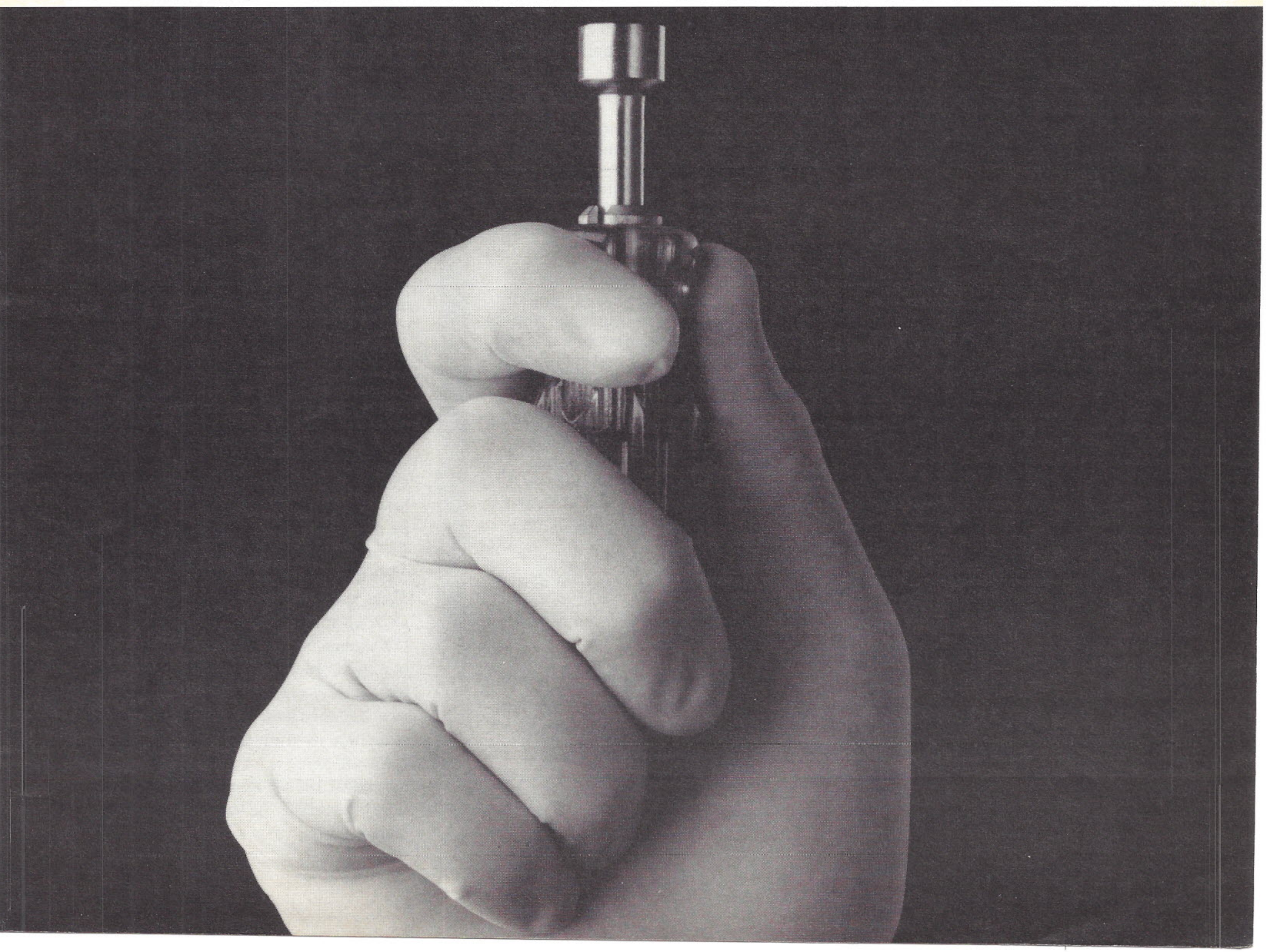

Educational Directions

Over the past two years, a joint research team from Duke University and the Lord Corporation has launched numerous research tasks on machine intelligence through touch sensors. The two coprincipal investigators are Professor Paul P. Wang of Duke University and Jack Rebman of Lord Corporation. A summary for each of the four central research themes follows, along with the name of the researcher directly connected with each project. For more information contact: Professor Paul P. Wang, Department of Electrical Engineering, Duke University, Durham, North Carolina, 27706.

A Pattern Recognition Scheme Using Natural Features for Low-Resolution Images

(Technical Report Robotics-EE-82-01, Richard J. Auletta.) We demonstrated a pattern recognition scheme based on the area, perimeter, and sides of a pattern using a 16 by 16 binary image. The goal was to distinguish between simple geometric shapes. A four-window binary boundary tracking edge detection algorithm is used to obtain a one-dimensional string from which the area, perimeter, and side information is derived. The area and perimeter are calculated directly from the edge detection algorithm while the side information is obtained through a methodology based on the theory of formal languages. A simple error function compares the extracted features with information stored in a standard mask of known shapes to determine which shape is generating the pattern.

Automatic Recognition of Low-Resolution Tactile Sensing Data Using Rapid Transformation

(Technical Report Robotics-EE-82-02, Kai-Kuang Ma.) From a practical viewpoint, a touch sensor should work well in minimally ordered and structured environments. Recognition features should be chosen to be independent of a silhouette's position and orientation. After some analysis, we selected a Rapid Transformation algorithm to extract the features. The sequential similarity detection algorithm with normalization is used to match test patterns against standard stored patterns.

Pattern Recognition Schemes for a Touch Sensor Array Based on Moment Invariant and Circle Search Methods

(Technical Report Robotics-EE-82-03, Masaki Togai.) Our goal was the recognition of geometrical patterns independent of position, size, and orientation within a touch sensing array. The recognition techniques had to be simple and capable of distinguishing low-resolution images. The implementation had to allow real-time processing using microprocessors. The study is primarily concerned with binary images, but the schemes developed can be used to recognize gray-scale images. To evaluate the algorithm's effectiveness, geometric shapes placed on a 32 by 32 touch sensor array were simulated by computer. The results show that this recognition scheme can achieve position, size, and orientation independence, as well as distinguish low-resolution images.

Recognition of Simple 3-D Geometric Objects Via a Low-Resolution Gray-Scale Tactile Sensor

(Technical Report Robotics-EE-82-05, Erik L. Hedberg.) Moment invariant algorithms were tested as a gray-scale pattern recognizer using six primitive geometric features. The primitive features include a vertex, straight edge, curved edge, flat plane, spherical plane, and cylindrical plane. Gray-scale patterns were obtained from an 8 by 8 array of low-resolution tactile sensors. Orthogonal bases (derived from the moments of various orders) of each pattern for each object were calculated and statistically analyzed from a learned base. A minimum distance classifier was used on the learned clusters to recognize primitive patterns from an entirely independent data set. Promising recognition rates were obtained for the low-resolution gray-scale tactile sensor.

UCLA EXTENSION

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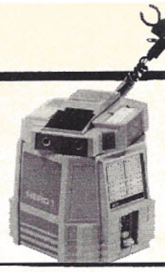

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NEW

VOICE COMMAND SYSTEM FOR HERO

MICROMATION proudly presents a new peripheral for HEATHKIT'S® HERO-I robot which elevates the robot to a new level of sophistication. We call this peripheral a Voice Command System (or VCS) because it not only consists of a voice recognizer, but also an advanced level machine language program for the robot which actually allows you to program robot movements by voice. We call the voice recognizer VOREC and the voice driven program VOCOL (VOice COmmand Language). Highlights of these two important parts of the VCS are described below.

VOREC*

VOREC is a powerful, microprocessor controlled, speech recognition board which mounts next to, and interfaces with, our HERO-I MEMCOM BOARD. The recognizer has the following principal features and specifications:

- Speaker-dependent recognizer with nearly instantaneous word recognition rates.
- Recognition accuracy about 98%.
- Vocabulary of up to 256 words (stored as 16 word groups with 16 words in each group for greater recognition accuracy).
- 16K of onboard static RAM of which 14K is battery backed to retain recognized word parameters during power down.
- RS232 port for receiving commands from, and reporting status and words recognized to, the host (HERO).
- Highly sensitive audio input circuitry requires only an external speaker for audio input rather than a microphone. (This allows robot to receive commands from up to 15 feet away.)
- Utilizes state-of-the-art high speed (HC) CMOS chips and the new CMOS 65CO2 microprocessor for ultra low power consumption. Complete board consumes an incredibly low 45 ma while active and 1 ma when inactive.
- Speech recognition is accomplished by a software algorithm contained in a 2K EPROM. (Future product updates will require only replacement of this EPROM.)

*These products are compatible with all personal computers

VOCOL

This software is even more amazing than the voice recognition hardware. VOCOL is like a high level language for the robot (such as BASIC) which supports both deferred and immediate execution modes. The only difference is in BASIC you "write it," and in VOCOL you "speak it." The software is provided on an EPROM which plugs into a memory socket on our HERO-I MEMCOM BOARD. VOCOL has the following principal features:

- When first run, the robot talks to you through a voice training session in which you are asked to repeat words in his command vocabulary three (3) times.
- Following this training session, you can literally talk in a program of movements for later execution, or command immediate movement by voice.
- The robot prompts you for a command and when received, repeats it back to you for verification. If verified and if in immediate execution mode, the robot will execute the movement. If in deferred execution mode, the robot proceeds to write a machine language program in his memory for later execution. When your program of movements is complete, you signify this with a "STOP" command. A "GO" command will then cause the robot to execute the program it wrote in memory. After execution, the robot returns to the command mode.
- Complete instructions and installation manual.

The Voice Command System manual contains a complete description of how to use the VOREC board under program control from HERO. The 6808 Source Code for VOCOL is available on an APPLE® DOS 3.3 disk at additional cost. This source code is compatible with the SC-6800 CROSS ASSEMBLER.

VOCOL Source Code **$55.00** (not sold separately) **TOTAL SYSTEM PRICE $595.00**

NEW

POET

This is an Artificial Intelligence program similar in concept to STORYTELLER, but more advanced. The program uses an advanced self-programming technique which allows the robot to speak self-generated, random three line Haiku poems on an endless list of subjects. After HERO speaks a poem and likes it enough, he will make a comment about it or do some meaningful body movement.

PRICE: TAPE (machine code) **$20.00** **PRICE:** DISK (source code) **$30.00**

HERO MEMCOM BOARD*

This product provides a means to develop programs for the robot using a personal computer, and expands the robot's memory with an additional 30K of RAM. This product includes:

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- An RS232 serial port for two-way communications between the robot and any computer having an RS232 serial port.
- Serial communications software in an onboard EPROM which allows uploading/downloading of programs via the serial port.
- Complete instruction manual and schematics.

PRICE $295.00

*These products are compatible with all personal computers.

APPLE-HERO COMMUNICATOR

This product provides the hardware and software necessary to implement two-way high speed parallel communication between an APPLE® computer and a HERO-I robot equipped with our HERO MEMCOM BOARD. It includes:

- A peripheral card for an APPLE that contains two 8-bit parallel ports with handshaking lines, and two 16-bit timers.
- Data transfer software for the APPLE board and for the HERO MEMCOM BOARD burned into two 2716 EPROMS. These programs provide ultra fast two-way communications.
- A disk containing heavily commented 6808 and 6502 source codes for the communications software. These source codes are compatible with the S-C MACRO ASSEMBLER and the S-C 6800 CROSS ASSEMBLER available for the APPLE from the S-C SOFTWARE CORPORATION.

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Circle 12

Robots in Batch Manufacturing

The Westinghouse APAS Project

Alfred B. Bortz
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According to many experts, assembly is the next growth area for the application of robotics. Bernard Miller, Manager of Programmable Automation at Westinghouse Electric Company's Industry Automation Division in Pittsburgh says, "It's my personal hunch that we are about two years away from significant application of robots in assembly."

Miller made that statement during a recent workshop at which Westinghouse presented results of its APAS (Adaptable, Programmable Assembly System) project to representatives from industry, government, and academia. He added that the two years might stretch to five, depending on the state of the economy, but he left no room for doubt that robots will soon move beyond "hot, heavy, and hazardous" to tedious and repetitive work.

Assembly takes place in industries ranging from automobile manufacturing to sophisticated electronics. Parts come in a wide range of shapes, sizes, colors, and materials. These parts are assembled using a variety of techniques. In all cases, the tasks are similar: take one piece after another, then put the pieces together according to a prescribed recipe until you achieve the desired result, a widget of one kind or another.

In most cases, the widgets are made in relatively small batches of tens or hundreds of identical items. Each batch is similar to the last, but requires a somewhat different recipe, producing a recognizably different product. This process is known as batch manufacturing and is characteristic, according to Westinghouse statistics, of 75 percent of all manufacturing and 22 percent of the gross national product of the United States.

Batch manufacturing is labor-intensive and not easily automated. Westinghouse, like many other American manufacturers, became concerned about a change in the historical pattern of productivity growth in the mid-1970s. Productivity began to level off, while costs continued to rise. The long-range profitability of batch manufacturing was clearly in jeopardy.

APAS: A Brief History. As the productivity growth pattern changed, the National Science Foundation (NSF) became concerned about the lack of industrial investment in the results of university research. To encourage application of promising new ideas, NSF began a new program called RANN, Research Applied to National Needs. The concerns of Westinghouse and NSF came together, and the result was a 1977 Westinghouse proposal for a project which led to APAS.

The project began with a $300,000 study phase, including $75,000 of Westinghouse money, to identify a product which would be well-suited for an APAS demonstration. Westinghouse soon settled on the fractional horsepower electric motor, a product it sells by the millions and manufactures in batches of a few hundred. Westinghouse small motors come in eight classes and 450 styles. Sales average 1 million motors per year, and a representative batch has 600 motors.

An assembly line averages 13 style changeovers per day. Assuming one hour per changeover, as much time is spent between batches as in assembling motors.

Westinghouse had found an application in need of an assembly system which adapts to variability in parts and positioning and which is programmable over a range of product variations. Westinghouse reported its findings to the National Science Foundation which agreed to fund Phase A of APAS with an award of $627,000 for the development of a detailed engineering design over an 18-month period. Westinghouse agreed to contribute $125,000 of its own funds.

The design called for a two-phase project to manufacture motors. In Phase B, Westinghouse would build an assembly line to make "end bell" subassemblies. Then the assembly equipment would be torn down and reused in Phase C, the manufacture of complete motors from end bell subassemblies, rotors, and stators.

Westinghouse incorporated the results of several important university research programs into the design, among them the Stanford Research Institute (SRI) vision system, Professor Geoffrey Boothroyd's

All photographs and figures used courtesy of Westinghouse Electric Corporation.

pioneering work in parts feeding at the University of Massachusetts, and the work on remote compliance, selective compliance, and other assembly techniques developed at the Charles Stark Draper Laboratories of MIT.

NSF agreed to fund the engineering cost of the project, one phase at a time, as long as Westinghouse agreed to purchase the equipment. Phase B began with a $303,000 commitment from NSF and $400,000 worth of equipment.

As frequently happens in a system design project, the original cost estimate was soon discovered to be low. In this case, the difference was remarkable. Programming cost estimates, especially in vision applications, soared, and Westinghouse requested an additional $455,000. The amount is remarkable, and so is the moral of the story: in developing a new system, software costs often equal or exceed hardware costs.

Even the additional $455,000 did not fully cover the cost growth in the system, but Westinghouse continued work for a full year after the NSF money ran out. To the credit of Westinghouse engineers, when the time came to display APAS, they showed its problems as well as its successes, and they noted the lessons learned from both.

APAS Lessons. One of the lessons, Bernard Miller pointed out, was that the robotics business is changing so fast that what started out as a significant advancement to the state of the art ended barely ahead of the industry five years later. "Don't lock yourself into a long-range program," he warned his audience.

For that reason, among others, NSF opted not to continue beyond Phase B. Alex Schwartzkopf of NSF praised APAS and noted that it had already taught the people of the manufacturing industry most of what they had hoped to learn.

Within a few years, the lessons of APAS will begin to pay off in batch manufacturing. For now, it is a useful case study of the limits of current technology and the possibility of renewed productivity growth in the near future.

The System. Photo 1 shows APAS in its final state, a rectangular transfer line arrangement with four robots and a considerable amount of original and conventional parts-handling equipment performing tasks at five stations. A sixth station was eliminated due to engineering difficulties.

Photo 1. The Westinghouse Adaptable Programmable Assembly System (APAS) in operation. End bell subassemblies for fractional horsepower electric motors are automatically assembled beginning at the robot station at the top center of the picture and proceeding counterclockwise to the station nearest engineer Brian Ottinger. APAS, funded jointly by the National Science Foundation and Westinghouse, provided many lessons in the application of automation and robot to batch manufacturing. According to Westinghouse, batch manufacturing is characteristic of 75 percent of all manufacturing and 22 percent of the gross national product of the United States.

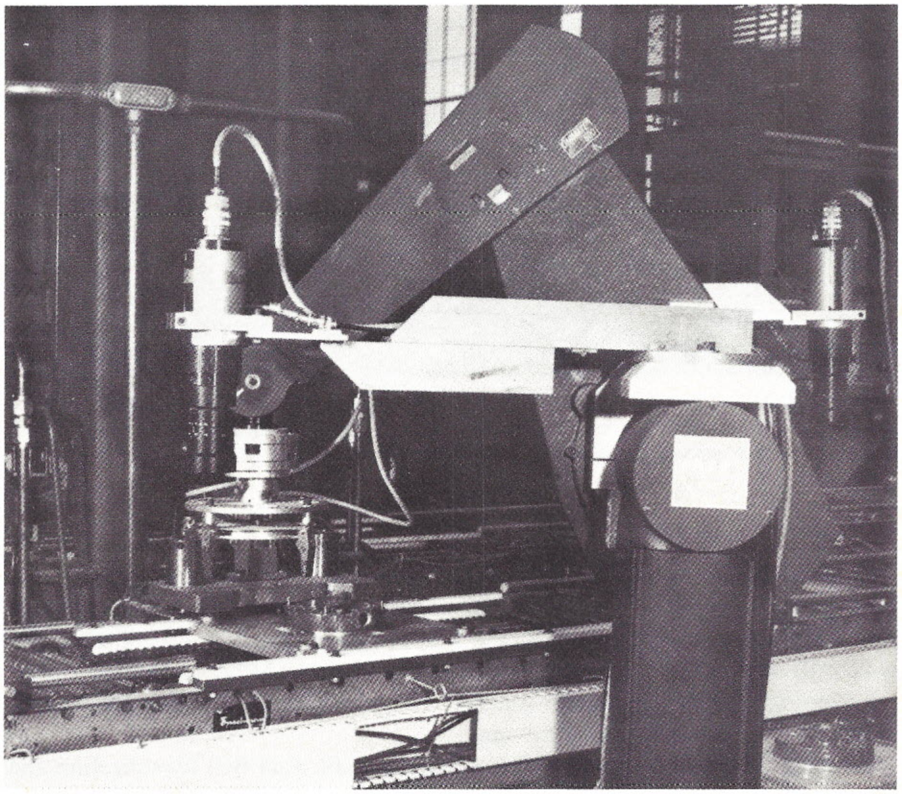


Photo 2. APAS station 101. APAS uses an extended version of the SRI vision software to identify the end bell to be assembled. Transmitted infrared light is the main source of illumination for the vision system. station 101 determines the end bell's orientation, then grips it, rotates it, and places it on a special pallet that preserves the orientation through the entire assembly process.

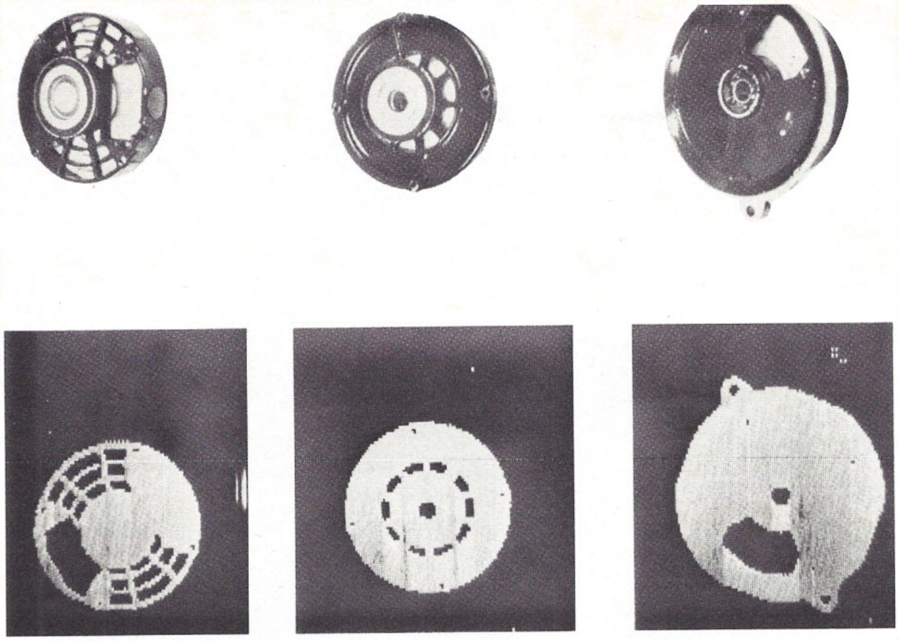


Photo 3. Typical end bells and their images as seen by the vision system at APAS station 101.

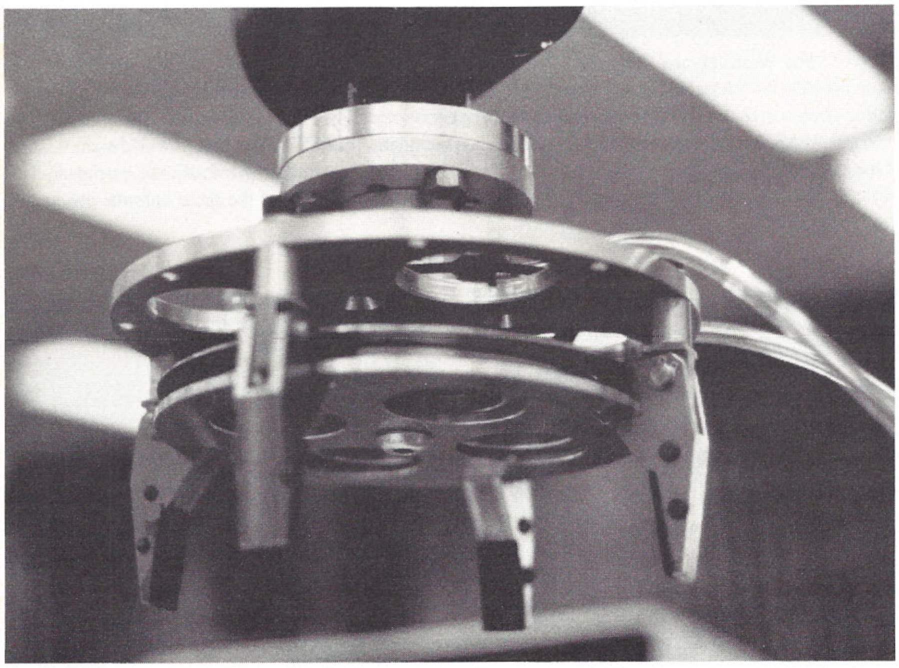


Photo 4. A detailed look at the station 101 end bell gripper. This gripper's mechanical design, as well as several other APAS elements were "a win/lose area," according to Bernard Miller, Manager of Programmable Automation at Westinghouse's Industry Automation Division.

That station employed fixed-purpose automation; thus it was not sufficiently important to the goals of APAS to justify the additional cost to complete its development.

Beginning with the Unimation Puma robot at the top center of the picture and proceeding clockwise to another Puma closest to the engineer, the picture shows the five stations, each of which had its own set of problems and lessons for the Westinghouse engineers. Each station also has lessons for people who are trying to make a judgement about what tasks are candidates for automation or robotization and about when the technology will be mature enough to automate or robotize those tasks.

Station 101: End Bell Identification and Palletization. Station 101, shown in photo 2, uses vision to identify end bells and determine their position and orientation. Building on the SRI vision system, Westinghouse engineers improved the communications interface between the camera and computer, adding preprocessing hardware to increase its speed. They also put substantial effort into improving the implementation of the image-processing algorithms.

Westinghouse determined that transmitted infrared light was the best choice for object illumination. The SRI system is a binary vision system (black-and-white only, without shades of gray), and variations in the reflectivity of the painted surface preclude the use of reflected light. The choice of an infrared light source minimizes problems due to ambient light.

The vision algorithms provide information about end bell characteristics such as total dark area and the number, size, and position of holes. The PDP-11/23 computer which controls this station as well as station 106 has a library of end bell characteristics in its memory; thus it can compare the image in the vision system to the expected characteristics of a variety of end bells. At present, this information is used only to make an accept/reject decision based on the end bell which the operator has told the station to expect. Photo 3 shows some typical end bells and their images as seen by the vision system.

If the end bell is rejected, the Puma arm uses the position information provided by the vision system to find it, pick it up with its specially designed gripper, and drop it in the reject bin. If the end bell is accepted, the Puma arm picks it up, rotates it, and places it on a specially designed pallet in the correct orientation.

The pallet design takes advantage of the fact that all 450 motor styles have four holes in a standard-sized square pattern. The pallet preserves the orientation, established at station 101, throughout the rest of the end bell assembly process.

The gripper design, according to Bernard Miller, is crucial to the success of this station. He describes it as "a win/lose area." The gripper must be well-suited to the end bell and must be somewhat forgiving of normal variations in the position of the end bell as determined by the vision system. Photos 4 and 5 illustrate the special features of the pallet and gripper.

Vision software is another win/lose area. All of the stations, including 101, are expected to complete their tasks within a 7.5-second cycle time (chosen to be equal to the production rate of five standard assembly lines). That time constraint places

significant demands on the vision software. Vision, however, is one area in which progress has nearly caught up with APAS. Miller says that commercial gray-level vision systems that can determine orientation within the required cycle time will soon be available.

Station 102: Making the Lubricating Wick. Station 102, deleted from the final APAS demonstration system after considerable work had been done on it, was designed to install a lubricating wick. At that station, fixed-purpose automation, based on a custom-made pick-and-place arm, added a felt wick and a plastic cage. These parts provide oil to the rotor shaft during motor operation.

Station 103: Cap, Ring, Washer. The third APAS station, station 103, barely visible in the rear on the right side of the transfer line in photo 1, is illustrated in detail in photo 6. At that station, three concentric parts are added to the end bell: a steel cap, a felt ring, and a metal thrust washer. At this station, the robot is simple, and the parts handlers and grippers are innovative. This station also injects two lubricants into the end bell.

The robot at station 103 is a simple Autoplace pneumatic arm with fixed stops for its rotational motion. Westinghouse modified the robot by adding a specially designed servocontrolled waist to provide more flexibility in positioning. When station 103 was built, no commercially available robots provided the degree of flexibility needed there. Some, like the Autoplace, provided too little flexibility; others provided too much. Choosing to modify the Autoplace was a deliberate experiment in robot economics.

Today, Westinghouse would have no need to experiment. There are now commercially available robots that provide the capability needed in this station at a much lower cost than the modified Autoplace.

Station 103, like station 101, is controlled by a PDP-11/23 computer. It was the first station to be built, and unlike the later stations, its interlocks are controlled by hardwired logic, which, of course, is not easily modified. The problems of hardwired interlock logic provided a lesson that was applied to all the later stations; all stations but 103 have programmable controllers for their interlocks.

The gripper design for this station, shown in photo 7, represents a significant technological advance. It is a three-stage device, using different holding techniques for each of the three pieces as it picks them up and nests them concentrically before adding them to the end bell. As in station 101, the gripper design makes the robot successful. Picking up three parts in one gripper rather than using three grippers make it possible to perform the operations at station 101 within the required cycle time.

Worth noting, although they are beyond the scope of this article, are the parts handlers. APAS experience convinced Westinghouse that using belts is superior to traditional vibratory feeding techniques. For a number of pieces, orientation or roundness are important. Skim blades and bumps cause pieces to fall into desired orientations or reject pieces in unwanted orientations. Moving cords squeeze felt rings, then spin them into nearly perfectly

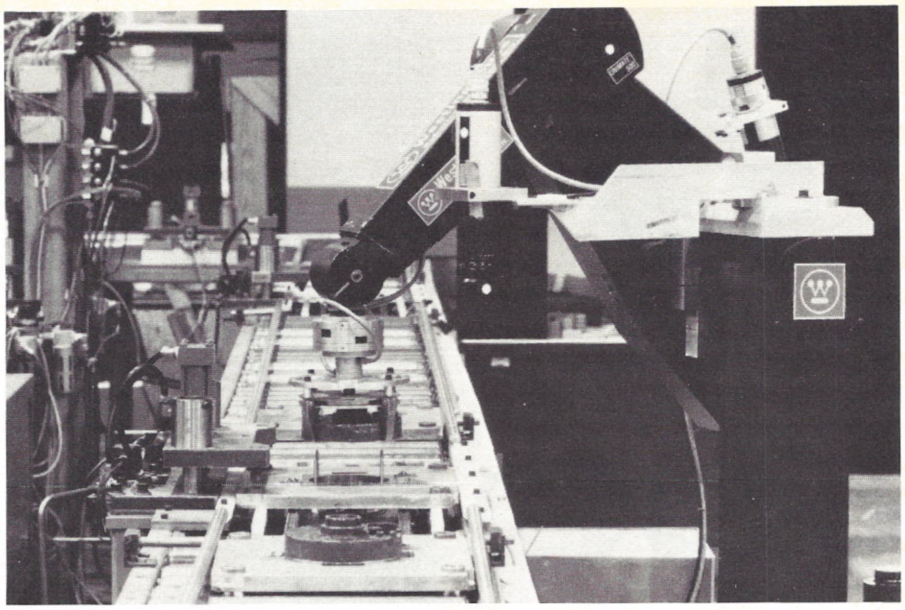


Photo 5. Another view of station 101, showing the robot holding an end bell just above the specially-designed pallet that preserves the end bell's orientation throughout the assembly process.

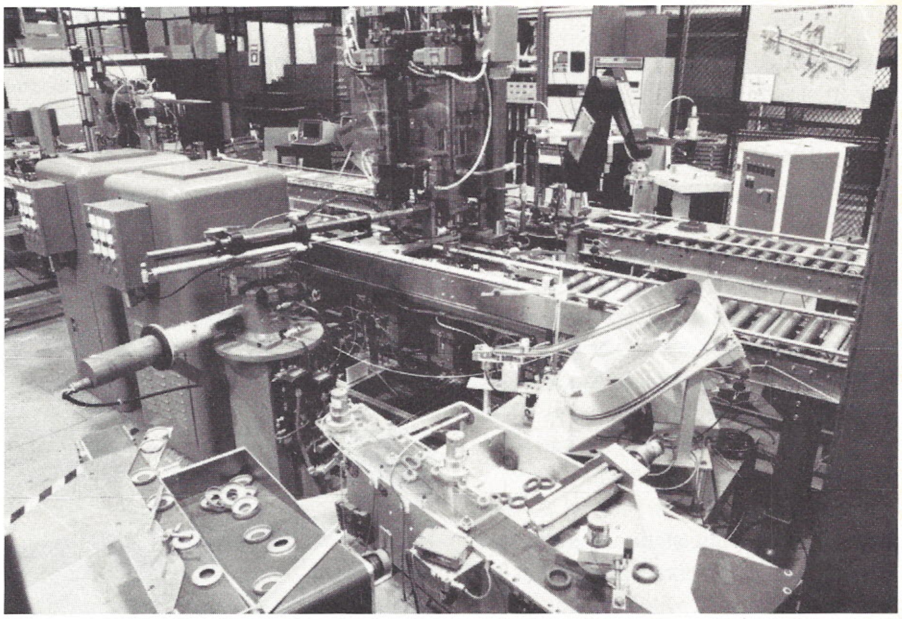
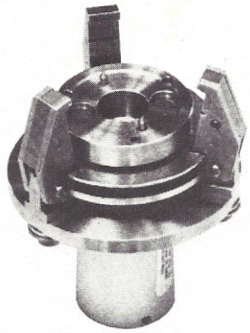


Photo 6. APAS station 103. At this station, three concentric parts are added to the end bell. The mechanical design of the gripper and part-feeding mechanisms were important aspects of this station. Westinghouse's decision to modify a commercially available robot to add one degree of freedom at considerable expense was a deliberate experiment in robot economics.



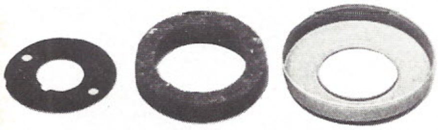


Photo 7. The gripper for station 103 and the three concentric parts to be gripped, assembled, and attached to the end bell.

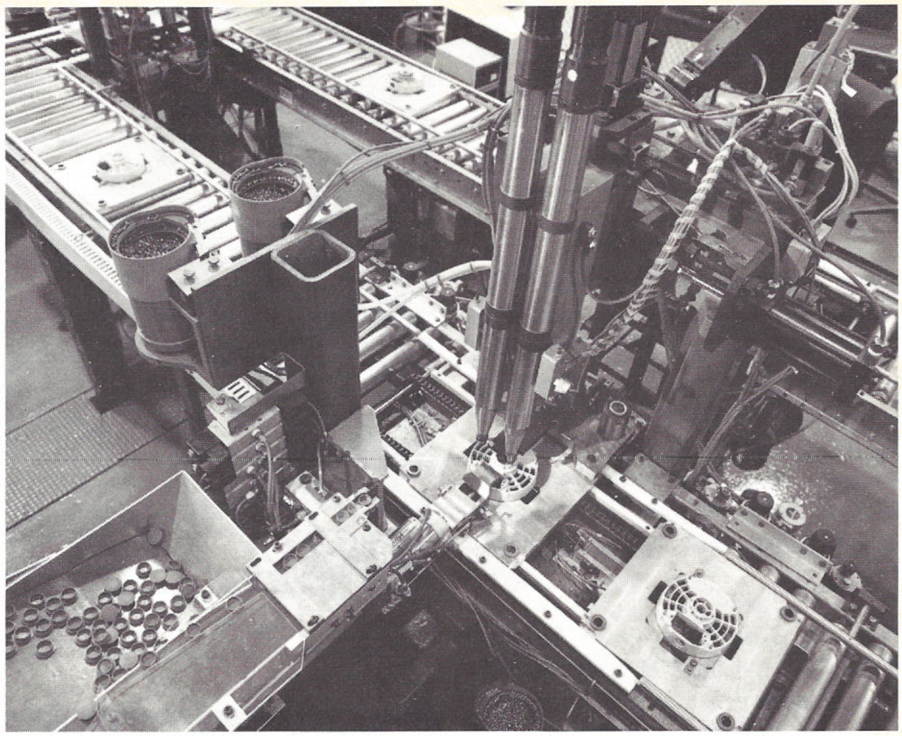


Photo 8. APAS station 104. This is strictly a hard automation station, at which three different operations take place at three different angles. If APAS was actually being used to produce these motors in a commercial line, the motors would probably be redesigned to simplify the operations at this station. The importance of designing for manufacturability was a major APAS lesson.

round configurations. These features appear in several of the photos.

Station 104: Screws, Plug, Contact Plate. The next station, station 104, is strictly hard automation (photo 8). Three operations take place from three different angles. From above, automatic screwdrivers, fed by vibratory screw feeders, drive three screws into each end bell as commanded by yet another PDP-11/23. A contact plate the size of a fingernail is screwed in from below. Finally, a plunger inserts a plastic plug into a hole on the side of each end bell.

Robot fanciers will be pleased to know that this nonrobotic station was the least reliable. Automatic screw driving was the major problem area. Misalignment, wrong screws, bad threads, and bad holes were the major headaches. If the station had been robotic, all of these problems could have been detected with sensors, and the first three problems could have been corrected at the station. The last, if detected, could have been used to mark the assembly for immediate rejection.

Station 105: Finishing Touches. Station 105 is in the foreground of photo 1 and in photo 9. At this station, depending on which of the two end bells of a given motor is being assembled, another Puma robot selects from among a mounting ring or an end cap and other pieces, possibly including a small plastic washer with two distinct sides. Once again, parts handling and pre-

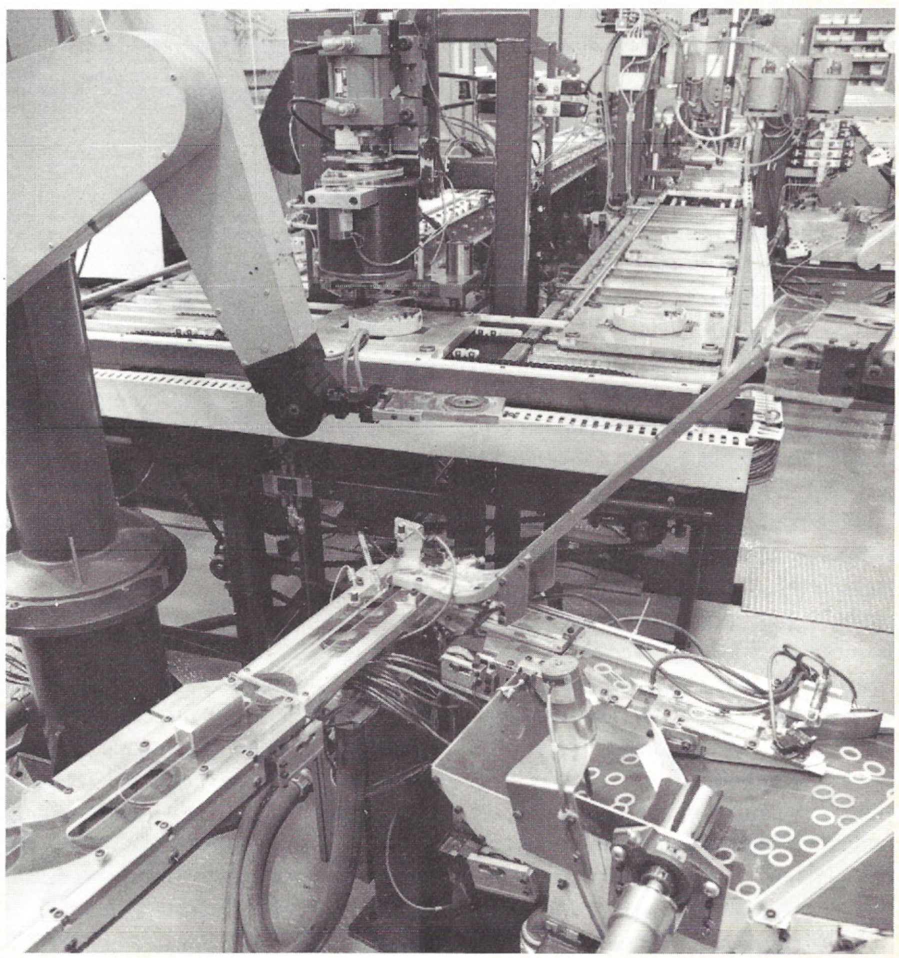


Photo 9. APAS station 105. This is the final assembly station. Again, the parts presentation techniques and gripper design provided important engineering lessons.

sentation techniques and a special gripper design were crucial.

After these finishing pieces are selected, the robot moves them to a machine that press-fits them onto the end bell. A torque sensor determines the correct angular orientation of a hexagonal hole in the mounting ring as it mates with a hexagonal feature on the end bell. Another PDP-11/23 controls these operations, with interlocks controlled by a programmable controller.

Station 106: Final Inspection. Vision once again comes into play at station 106, shown in photo 10. The finished subassembly is examined from top and bottom by an Object Recognition Systems, Inc., (ORS) template matching vision system. Template matching is much simpler and less expensive than the vision system at station 101. It can be used because the end bell's position and orientation were determined at station 101 and preserved by the pallet.

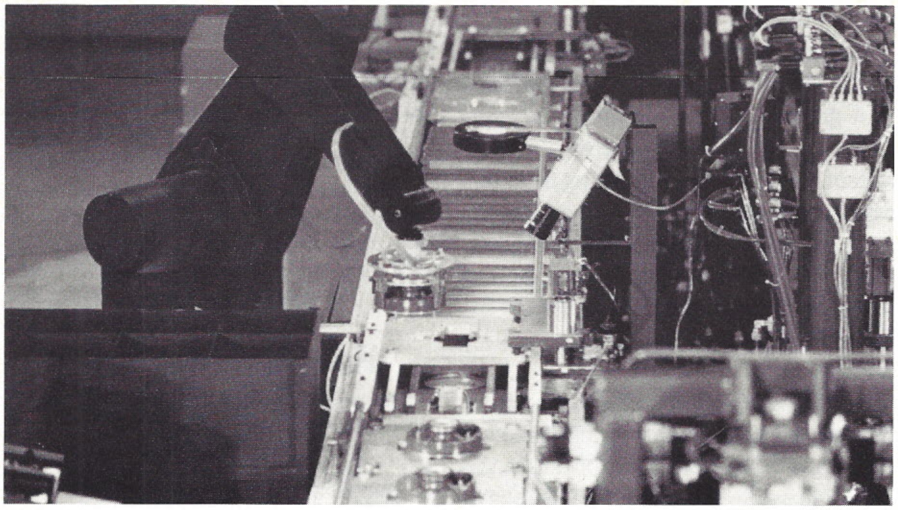


Photo 10. APAS station 106. Here, the completed end bell subassemblies undergo final inspection. The template-matching technique Westinghouse decided to use did not produce completely satisfactory results.

The images from the camera are compared to templates stored in the memory of the ORS controller. After the inspection, the Puma robot picks up the finished piece. If a significant number of pixels differ between the image and the template, the subassembly is rejected; otherwise the Puma places the subassembly in one of an array of boxes.

If this were not the final step of this demonstration, the subassembly would not be placed in a box, since that action destroys knowledge of the subassembly's orientation. In an actual automated factory, the end bell subassembly would be placed on another pallet after inspection and transferred, with its orientation carefully preserved, to another transfer line, much like the one planned for APAS Phase C.

The results from this inspection technique were not entirely successful, according to Brian Ottinger, the Westinghouse engineer who appears in photo 1. The vision system had to be trained by showing it several valid images. If the vision system was trained with only one image, then good end bells were rejected. On the other hand, if it was trained by "seeing" a number of good end bells which covered the normal range of manufacturing variation, then

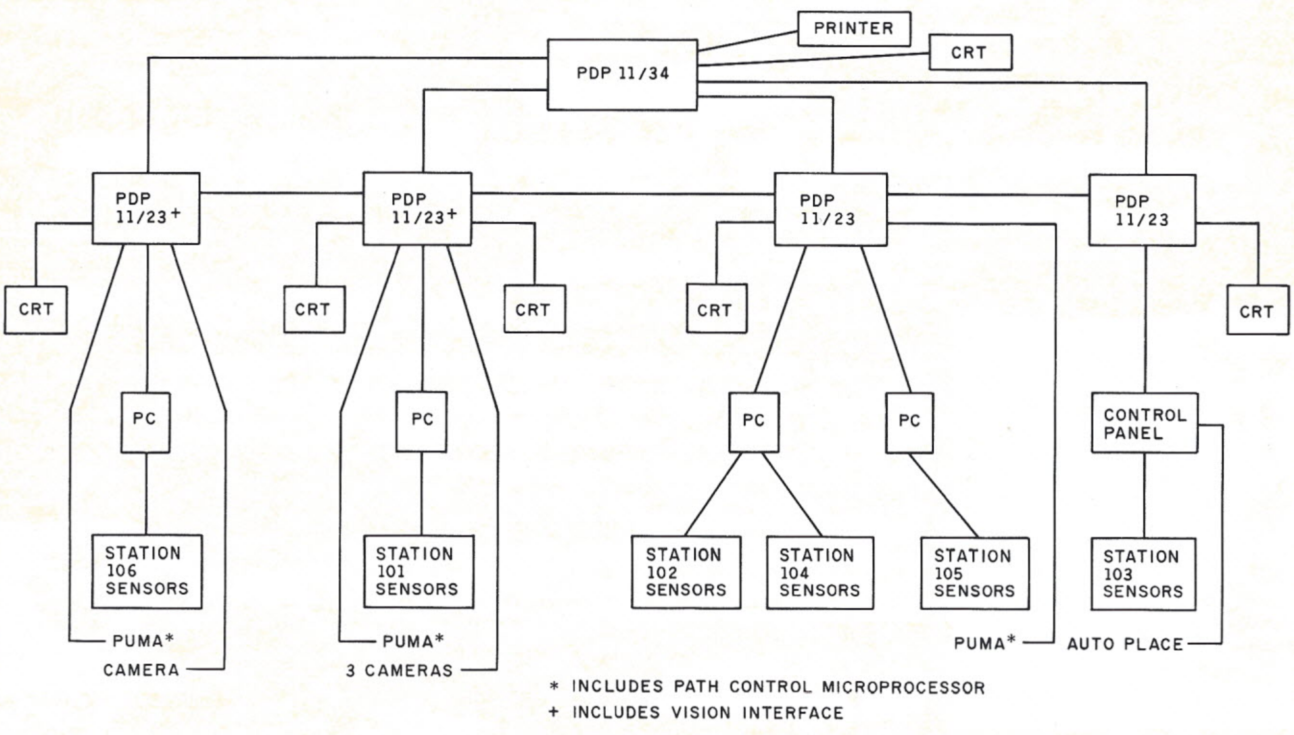


Figure 1. The APAS computer, sensor, and control arrangement.

small features which should cause rejection, such as missing screws, passed the final inspection.

Computer Organization. Figure 1 shows the computer organization of APAS. It is a hierarchical, distributed control system. Each station has its own local control computer, a PDP-11/23 running under the RSX-11S operation system, with the exception of one PDP-11/23, which supports the vision system and communicates with the Pumas at stations 101 and 106. That computer runs under the more sophisticated RSX-11M operating system and can serve as a backup to the system master computer, a more powerful PDP-11/34 also running under RSX-11M.

The PDP-11s are interconnected and communicate via a local area network called DECnet. The master computer, in theory, could be linked to a major mainframe computer responsible for overseeing the total plant operations. Information generated from an APAS line could be combined with inventory and quality control information, leading to greater efficiency and better quality control.

After APAS. Now that the APAS project has reached its end, Westinghouse and the National Science Foundation are looking to the past to assimilate its lessons and to the future to apply them. Bernard Miller's warning about avoiding long-term robotic projects remains particularly apt. The industry and the technology are changing too fast to allow prediction of what will happen much more than a year in advance, and key technical people will continue to be in exceptionally high demand (and therefore extremely mobile).

The latter problem particularly afflicted APAS and caused, no doubt, a significant cost growth. It certainly should be considered in any plans to develop a robotic system, for batch manufacturing or otherwise. Another lesson, which is most evident from the awkward multidirectional operations of station 104, is that automation of batch manufacturing may require or inspire redesign of the product being manufactured.

But the most important conclusion to be drawn from APAS is that batch manufacturing can be automated and, no doubt, will be automated in the near future, thanks to the ingenuity of mechanical engineers, electrical engineers, computer scientists, and roboticists. It will spread slowly because of the need for capital formation and the redesign of products to make them more compatible with robotics and other new techniques. But it will happen. The National Science Foundation, with its $1.7 million investment, and Westinghouse, with an equivalent one, may not have surveyed enough terrain to lay out a complete road map, but they have certainly shown us where we are going. □

ABOUT THE AUTHOR

Alfred B. Bortz is on the technical staff of Carnegie-Mellon University, where he is Assistant Director of the Magnetics Technology Center. He is also a freelance writer of technical books and articles for nonscience audiences, including children. This article is based on a chapter of his forthcoming book, tentatively titled *A Decision-Maker's Guide to Keeping Abreast of Robotics*, to be published by Van Nostrand Reinhold.

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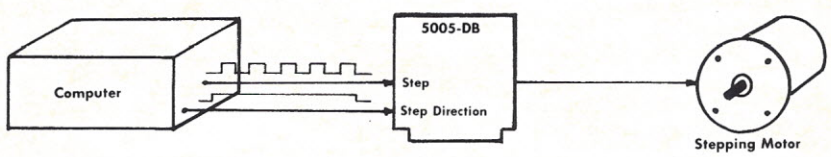

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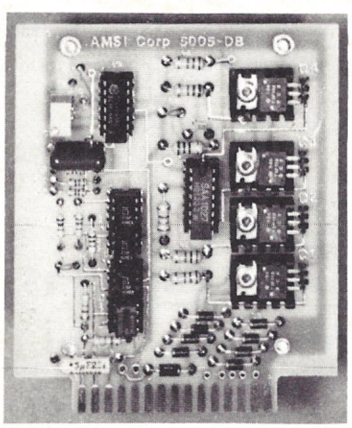

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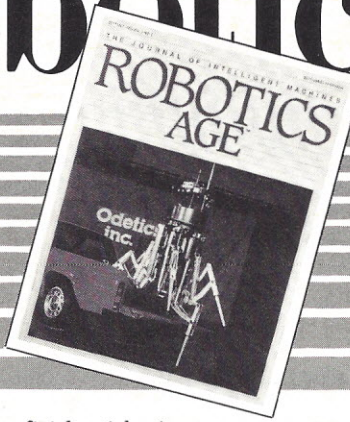

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Five degrees of freedom, low cost, microcomputer control, accurate repeatable positioning, and usefulness—these features all describe the robot we built in the Wright State University laboratories. Our goal was to build such a robot and have it perform a desired task. Our robot, called Super Armatron, started out as the Tomy Armatron robot. Originally distributed by the Tomy Corporation, the inexpensive Armatron is now available in Radio Shack stores around the country.

Our definition of functional included position sensing and computer control of each joint. These two features allow Super Armatron to perform complex tasks under program control. Super Armatron is equipped with a teach-mode capability and a simple, three-instruction robot language for moving the arm.

The Arm. As purchased, the Armatron arm is moved with two joysticks, which control the five axes of motion and open and close the gripper. Photo 1 shows Super Armatron after we completed the initial hardware modifications. We removed the joystick controls and replaced them with solenoid actuators. Both the solenoids and the Armatron are mounted on an aluminum plate. We added Hall-effect sensors to the waist, shoulder, elbow, wrist, and gripper. An optical encoder determines wrist roll positioning.

A single DC motor located in the base provides the motive power for the entire arm. Each joint is controlled through a series of plastic gears and metal rods. Although the waist joint is capable of 360-degree rotation, we limited this motion to 180 degrees to protect the added electrical wires. The shoulder joint moves up 25 degrees and down 40 degrees, while the elbow joint moves 90 degrees to the left or right.

The elbow joint is coupled to the wrist so that when the elbow moves to the left, the wrist rolls counterclockwise (as seen from the elbow) and vice versa. Cross-coupling also occurs between the wrist's pitch and roll axes. The wrist rolls counterclockwise when the pitch axis (limited to ± 90 degrees) moves up, and clockwise when the pitch axis moves down. Although the wrist can roll 360 degrees, we limited its motion to ± 180 degrees to prevent damage to the wiring harness.

The Computer. The computer system consists of a PDP-11/23 running the RT-11 operating system that is connected to an LSI-11 to which the compiled programs are downloaded. The control program is written in Micropower Pascal and uses several prewritten I/O driver routines coded in assembly language.

The LSI-11 contains analog-to-digital converters with four decimal digit accuracy for sensor input, and a parallel I/O (PIO) board for communicating with Super Armatron and its 12 joint-control solenoids.

The Software. The three basic arm movements are: move from point A to point

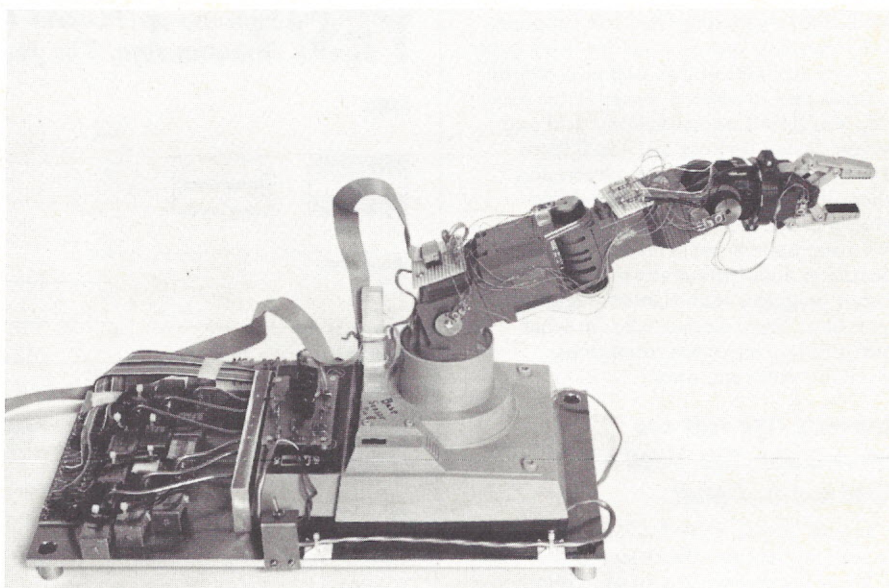


Photo 1. Super Armatron after hardware modifications. Twelve solenoid actuators control the five axes of motion and the gripper. Hall-effect sensors provide position feedback for the waist, shoulder, elbow, wrist, and end-effector gripper. The plexiglass rod by the waist joint prevents the waist from rotating a full 360 degrees, which would pull off the Hall-effect sensor wiring harness.

B; grasp; and release. We decided that the arm would always start at a known point before beginning a task. We use the teach-mode to move one joint at a time until the arm is in the desired starting position, and then store the sensor readings for that point. The teach-mode makes the arm highly adaptable to any application.

The program is designed to store up to 50 points. The "teacher" is responsible for ensuring the arm has a clear path from one point to another, since obstacle avoidance is not built in. After a series of stopping points are stored, the program is placed into the run mode. The arm moves to the starting point and proceeds through the preplanned movements.

Due to the power considerations of simultaneously moving multiple joints, we decided to move only one joint at a time. For any one step, the waist joint moves first, and movement proceeds outward towards the wrist. This decision also simplified the control program.

The task we wished to complete was the Towers of Hanoi game. We chose this application since it is familiar to most computer science students. We used three rings, which makes for only 12 stopping points. Figure 1 shows the eight different disk configurations encountered while solving the puzzle. The main program in listing 1 shows how the disks are moved.

Three points were defined on each of the three poles and one point above each pole. To move the first ring, the arm moves from the starting position to a point above the first pole (point 4) with the gripper open. The arm then moves to point 3, grasps the first ring, continues back to point 4, continues to point 12, and down to point 9, where it releases the ring and completes the first move. Similar move cycles continue until all three rings are on the third pole. To prevent the arm from hitting any obstacles, we instructed the arm to move to the "holding" position above each pole before moving to the next position. Photo 2 shows Super Armatron executing the programmed task.

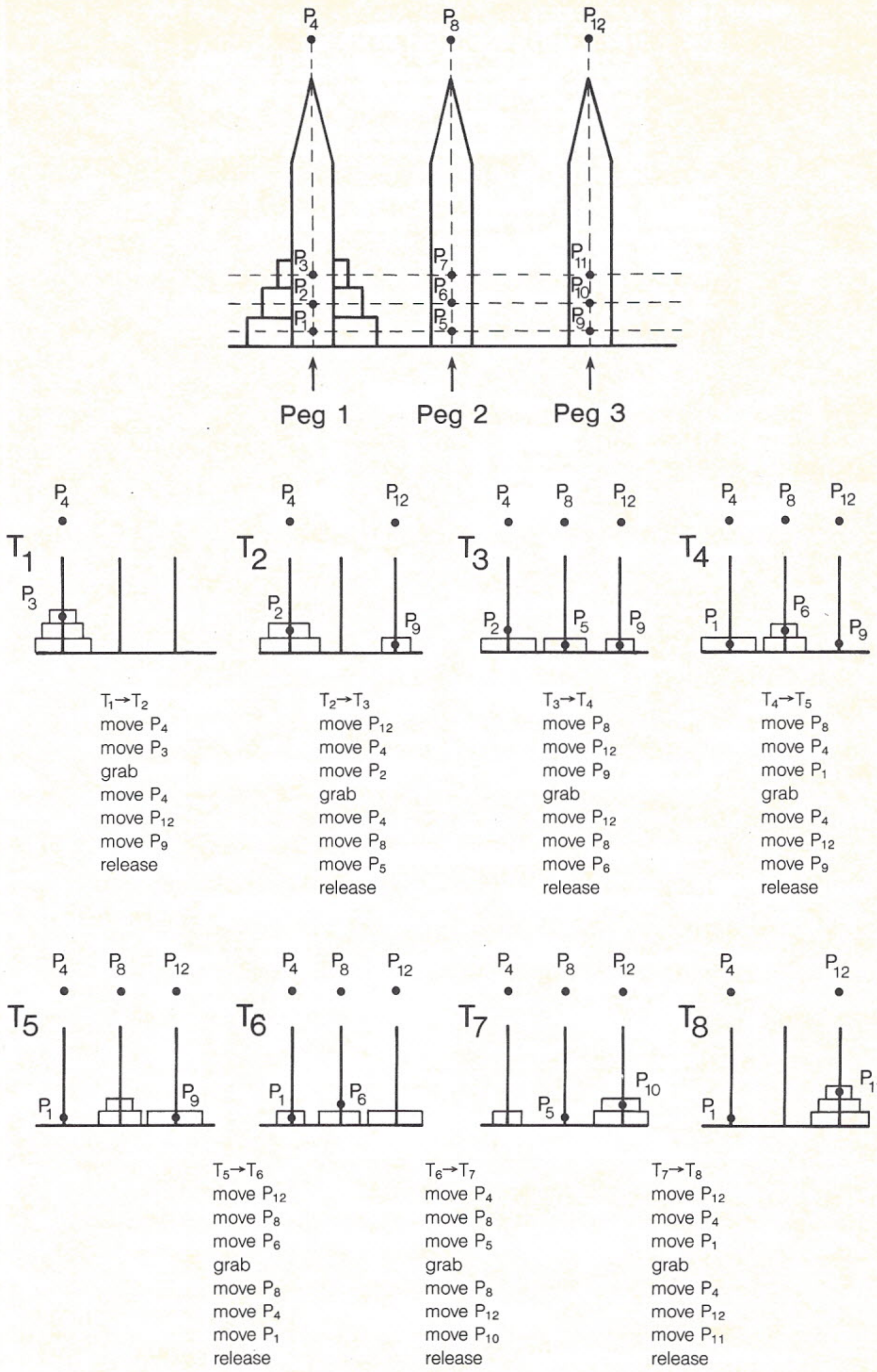


Figure 1. The Towers of Hanoi problem is used to illustrate the robot control language. This task requires accurate position sensing and movement during the execution of the 55 commands needed to complete the game. When using the robot control language, the operator must define only the 12 predetermined positions (P1 through P12) and the order in which the rings must be moved between them. The main progam listing shows how the moves are made.

The Control Language. The program in listing 1 contains all of the procedures used to control the arm. The prewritten I/O routines are not included since they are hardware dependent.

The first section of the program contains all of the necessary tables and variables. Table POS TABLE is used to store the Hall-effect sensor readings for each stopping position. The vector JCW is the Joint Control Word, which is sent to the PIO board to control joint motion. The associated comments describe the joint motion attached to the solenoid number.

In Micropower Pascal, all procedures must be defined before they are invoked. We will explain the procedures (MOVE, GRAB, RELEASE, and TEACH) in the order in which they appear.

The MOVE procedure moves the arm, one joint at a time, starting with the waist. The position to which we want the arm to move is compared to the current position. Since the Hall-effect sensor on the waist

```
PROGRAM ROBOT (INPUT,OUTPUT);
        TYPE     VECTOR = ARRAY [0..15] OF BOOLEAN;
        TYPE     TABLE = ARRAY [0..50,0..15] OF INTEGER;
        VAR      J,MOV,JOINT,DIRECT,KEEP_MOV,STORE,I,POS,K : INTEGER ;
                 GPOSMIN,GPOSMAX,HEMI,OLDHEMI,POSMAX,HFLAG,STOP,INISTOP : INTEGER;
                 GPOS,WPOS,SPOS,EPOS,PPOS,RPOS,WWPOS : INTEGER ;
                 FINALPOS,ROLL1,ROLL2,NEW_ROLL1,NEW_ROLL2 : INTEGER;
                 JIN,WR_JOINT : INTEGER;
                 A,B,AN,BN,S1,S2,S3,S4,S1N,S2N,S3N,S4N,CU,CD : BOOLEAN;
                 HA,HB,OLD_WCOUNT,WCOUNT,HIVALUEA,HIVALUEB : INTEGER;
                 JCW : VECTOR ;
                 POS_TABLE : TABLE ;
        PROCEDURE WRTPIO (JCW : VECTOR);EXTERNAL;
        PROCEDURE INIPIO ; EXTERNAL;
        FUNCTION GETADC (S, D : INTEGER) : INTEGER; EXTERNAL;
        FUNCTION RDPIO : VECTOR;EXTERNAL;
        PROCEDURE CORR_WRIST ; FORWARD;
        PROCEDURE WR_COUNTER ; FORWARD;

        THE FOLLOWING PROCEDURE WILL BE THE TEACH MODE FOR THE ARMATRON
        ROBOT.

                 SENSING POSITION OF THE ARMATRON


          14-PIN CABLE                         A/D CABLE
  AXIS       PINOUT        CONNECTED TO      PINOUT     SIGNAL

SHOULDER       1           CONNECTED TO        3        CH 1
ELBOW          2           CONNECTED TO        5        CH 2
PITCH          3           CONNECTED TO        7        CH 3
ROLL4          4           CONNECTED TO        9        CH 4
ROLL5          5           CONNECTED TO       11        CH 5
GRIPPERS       6           CONNECTED TO       13        CH 6
WAIST          8           CONNECTED TO       15        CH 7

  IN ADDITION: 7(GND)      CONNECTED TO       18        AMP L


                 READING WRIST ROLL USING PIO


          14-PIN CABLE                         PIO CABLE
  AXIS       PINOUT        CONNECTED TO      PINOUT     SIGNAL

ROLL4          4           CONNECTED TO      J1-37      A I/O 0     (LOWER SENSOR)
ROLL5          5           CONNECTED TO      J1-39      A I/O 1     (UPPER SENSOR)

  IN ADDITION: 7           CONNECTED TO      J1-26      GROUND

NOTE:  FOR CORRECT OPERATION OF THE PIO BOARD, J1-22, "USER RDY B", MUST BE
       CONNECTED TO GROUND (J1-26).



        SOLENOIDS ARE ACTIVATED WITH A LOW INPUT.

CONVENTION:
WAIST, ELBOW:  VIEWED FROM ABOVE.    ROLL:  LOOKING INTO GRIPPERS.


                             16-PIN CABLE                     PIO CABLE
SOLENOID    MOVEMENT           PINOUT       CONNECTED TO      PINOUT        SIGNAL

   0        SHOULDER DOWN      1            CONNECTED TO      J1-14         B I/O 0
   1        SHOULDER UP        2            CONNECTED TO      J1-12         B I/O 1
   2        WAIST CTR-CLKWSE   3            CONNECTED TO      J1-13         B I/O 2
   3        WAIST CLKWSE       4            CONNECTED TO      J1-11         B I/O 3
   4        ROLL CLKWSE        5            CONNECTED TO      J1-16         B I/O 4
   5        ROLL CTR-CLKWSE    6            CONNECTED TO      J1-9          B I/O 5
   6        PITCH DOWN         7            CONNECTED TO      J1-15         B I/O 6
   7        PITCH UP           9            CONNECTED TO      J1-10         B I/O 7
   8        ELBOW CTR-CLKWSE   10           CONNECTED TO      J1-4          B I/O 8
   9        ELBOW CLKWSE       11           CONNECTED TO      J1-1          B I/O 9
   10       GRIPPERS OPEN      12           CONNECTED TO      J1-7          B I/O 10
   11       GRIPPERS CLOSED    13           CONNECTED TO      J1-8          B I/O 11


            IN ADDITION:       8            CONNECTED TO      J1-26         GROUND

NOTE:  FOR CORRECT OPERATION OF THE PIO BOARD, J1-22, "USER RDY B", MUST BE
       TIED TO GROUND (J1-26).


                 STORE = 1 SELECTS POSITION TO BE STORED
                         0 DO NOT STORE POSITION
}
PROCEDURE MOVE(POS : INTEGER);



        {MOVE WAIST}

BEGIN
        WPOS := GETADC(7,1);
        POSMAX := WPOS;
        HFLAG := 0;
        IF WPOS <> POS_TABLE[POS,7] THEN
           BEGIN
              IF POS_TABLE[POS,8] = OLDHEMI THEN
                 IF OLDHEMI = 0 THEN
                    IF WPOS > POS_TABLE[POS,7] THEN
                       JOINT := 2
                    ELSE
                       JOINT := 3
                 ELSE
                    IF WPOS > POS_TABLE[POS,7] THEN
                       JOINT := 3
                    ELSE
                       JOINT := 2
              ELSE
                 BEGIN
                 HFLAG := 1;
                 IF OLDHEMI = 0 THEN
                    JOINT := 3
```

Listing 1. The robot control routines are written in Micropower Pascal from Digital Equipment Corporation.

does not provide absolute position, we must also know which "hemisphere" contains the next position. Depending on which "hemisphere" the next position is in, the arm is moved either clockwise or counterclockwise. The waist movement continues until the hemisphere and Hall-effect sensor reading match the values taken from the position table.

The shoulder is moved next. The direction is easily determined, since the Hall-effect sensor provides readings from a minimum to a maximum value throughout the range of movement. The elbow motion is started and allowed to continue until the values match.

The elbow movement direction is determined in the same manner as the shoulder direction. When the elbow is moved, however, we must consider the mechanical cross-coupling with the wrist. A wrist correction routine, which will be explained later, is also called.

The arm's pitch is adjusted in the same manner as the shoulder and elbow. Since the pitch movement also experiences a cross-coupling interaction with the wrist roll motion, the wrist correction routine is called. The final arm movement is wrist roll. Wrist roll positioning is determined using optical encoders. Basically, the wrist is rolled in the proper direction until a position counter matches the value stored in the position table.

Procedures GRAB and RELEASE simply cause the gripper to close or open. The gripper moves to a predetermined position defined by a special variable. Although our program uses a constant value, the value could be read from the position table. This change would allow the arm to grasp various sized objects while executing a single task.

The TEACH procedure begins by initializing the PIO board. The wrist is then rolled to the mechanical stop for its initial position. While the wrist is rolling, the high values obtained from the optical encoders are read and stored to provide a reference for future wrist roll movements. An arbitrary value of 100 is assigned to the roll count to prevent it from becoming negative.

Once everything is initialized, the TEACH program displays a menu of arm movements and allows the operator to move one joint at a time. The operator stops arm motion by pressing a switch, which is connected to an analog-to-digital converter. The operator can then decide either to store the current position or to continue moving

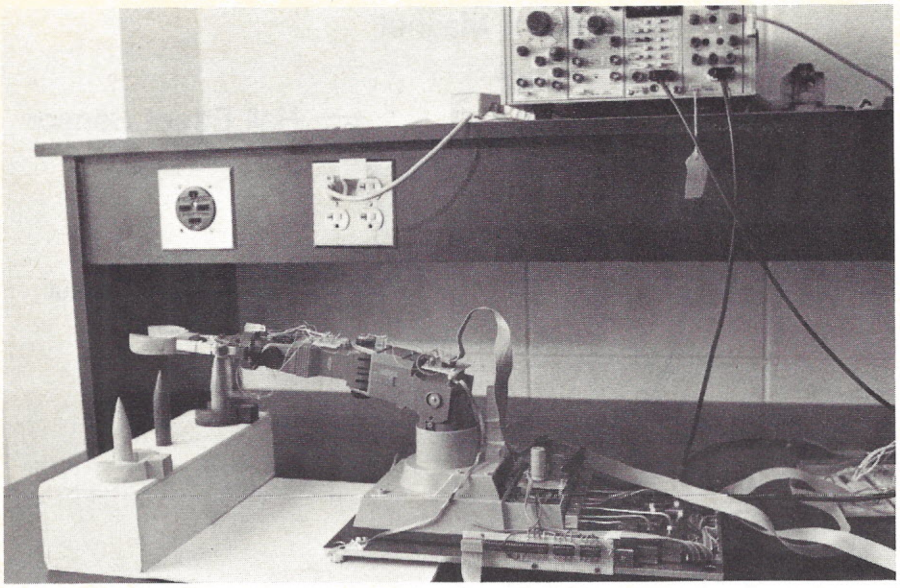


Photo 2. Super Armatron is programmed to complete the Towers of Hanoi game, implemented here using three rings. This game requires moving the three rings located on the first pole to the last pole. The rules are simple: move one ring at a time, and never place a larger ring on top of a smaller ring. Super Armatron is caught in the process of moving one ring to a new location.

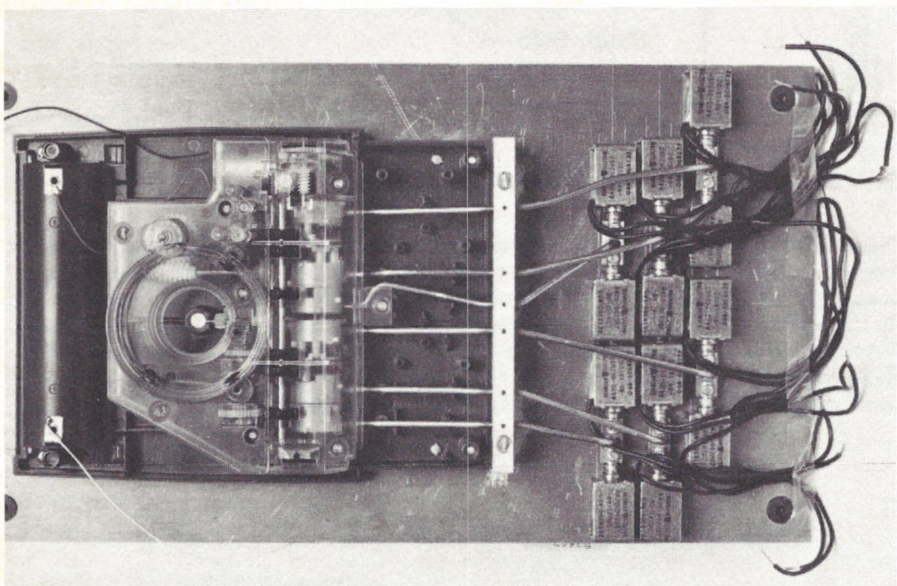


Photo 3. Top view of Super Armatron with the cover removed. All joints are controlled by one DC motor. Joint movement is achieved by activating one of the six pairs of solenoids. Two solenoids are required to control one joint resulting in two opposite motions. The solenoid pairs are mechanically connected with a metal plate.

the arm. If the position is to be stored, the operator must enter a value indicating the hemisphere in which the waist is positioned. The operator can then proceed to another position. When all the positions are stored, the TEACH procedure returns control to the main program.

The wrist correction procedure counteracts the undesirable cross-coupling of the wrist and elbow and keeps the wrist in its present position as the elbow or pitch is adjusted. The procedure works by watching the wrist counter value. If the wrist counter value changes by two, the elbow or pitch movement is stopped, and the wrist is rolled until the counter returns to its initial value. The elbow or pitch movement is then restarted.

The wrist counter procedure performs a set of Boolean functions on the wrist roll optical encoder inputs. Given the initial and next position of the wrist, a state table can be devised to ascertain the roll direction. The roll direction is then used to determine whether the roll counter must be incremented or decremented.

The main program calls either the TEACH, MOVE, GRAB, or RELEASE procedure. In the Towers of Hanoi game application, the movements are in a loop so that the game is played continuously. These four function calls provide the flexibility needed for many different applications. This main program, with only minor modifications, could be designed to repeat a wide variety of functions endlessly.

Additional Hardware. The arm's joint movements are controlled by an LSI-11 microcomputer, which actuates solenoids through a parallel output port. Joint position is sensed and fed back to the computer by Hall-effect transducers, which detect the orientation of a small, round magnet placed at each joint. Each Hall-effect sensor produces an analog output voltage, which is connected to one channel of a 12-bit analog-to-digital converter in the LSI-11. Since the roll axis could not easily be sensed with this technique, we implemented an optical shaft encoder using two TRW reflective object sensors.

Motion Control. Photo 3 is a top view of the Armatron base with the cover removed, exposing the modifications we made to provide for computer control. Each joint is controlled by stopping the rotation of one of the six plastic cylinders seen in the photograph. Each cylinder has five tabs around its circumference. The middle tab is for stop; the two tabs on the left provide two speeds in one direction; and the two tabs on the right provide two speeds in the opposite direction.

The LSI-11 controls the arm by actuating solenoids, which in turn move metal rods (fingers) that catch on the plastic tabs. This mechanization provides for one forward speed, one reverse speed, and stop. Each metal finger pivots on a pin in the metal block at the edge of the plastic base. We selected this method to allow room for mounting the 12 solenoids and to keep the solenoid stroke short.

Two opposing solenoids are required for each finger. A small metal plate connects their two plungers. Each solenoid has a spring around its plunger so that both plungers are out when the solenoids are off. This places the finger at the middle tab stop position. Actuating one solenoid moves the finger to a tab which engages a gear and

produces motion about one joint. Actuating the other solenoid in the pair causes motion in the opposite direction. The controlling program must ensure that both solenoids are never actuated simultaneously, since the result is indeterminate.

The solenoids, which we obtained from electronic surplus for $1.50 each, are manufactured by Guardian Electric (part number A420-062057) and are intended for 18V operation. We actuated the solenoids with a 12V supply from a quad high current driver, ULN 2064NE. When actuated, the solenoid draws 200mA.

We added two mechanical stops to prevent damage to the wires connected to the arm. One stop is mounted on the base to prevent 360-degree rotation about the waist. The other mechanical stop is mounted on the wrist to prevent 360-degree rotation about this joint.

Sensing Joint Position. The orientation of the six joints in the arm must be measured to determine the arm's position. The joints are at the waist, shoulder, elbow, pitch of wrist, roll of wrist, and gripper. The first four joints and the gripper are sensed by measuring the field from a magnet mounted on the joint. The wrist roll is sensed using optical encoding techniques.

The magnet is a ¾-inch diameter Alnico 2 disk (Permag part number SD1701), magnetized as a two-pole rotor along the diameter. A 3/32-inch diameter hole is drilled in the middle. The sensor is a Micro Switch (part number 915512-2), linear output Hall-effect transducer, which requires a voltage between +8V and +16V. This transducer has three leads: Vcc, ground, and output. The sensor's output is Vcc/2 with no magnetic field. The transducer is mounted over the edge of the magnet, with about ⅛-inch clearance.

In this application, using a 10V power supply, the output voltage varies approximately sinusoidally with magnet angle of rotation from about 8V at one pole of the magnet to 2V at the other pole. Figure 2 shows the typical positioning of the Hall-effect transducer and voltage output as a function of the magnet angular orientation. The output of each Hall-effect transducer is connected to an input channel of a 0 to 10V, 12-bit analog-to-digital converter in the LSI-11.

Sensing Wrist Roll Position. The wrist has no location suitable for placing a round

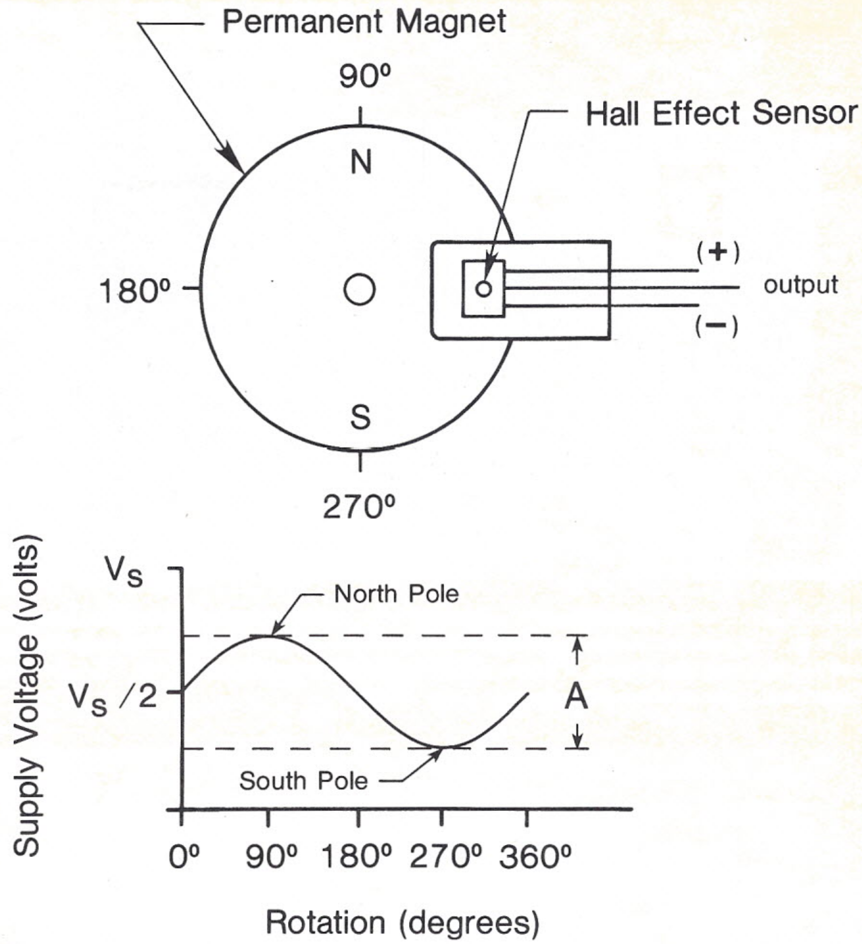


Figure 2. The Hall-effect sensors provide absolute position information if they are used within a dynamic range of approximately 180 degrees. The output voltage from 90 degrees to 270 degrees is continuous and unique. From 180 degrees to 360 degrees, however, the output voltage is not unique. It is necessary to position the magnets accurately for the joints with a limited range. Since the waist joint has a range greater than 180 degrees, we use the slope of the tangent line to determine the absolute position. The amplitude (A) of the Hall-effect sensor's output signal is a function of the magnetic field strength. The amplitude reaches a maximum when the Hall-effect sensor is positioned as close to the magnet as possible.

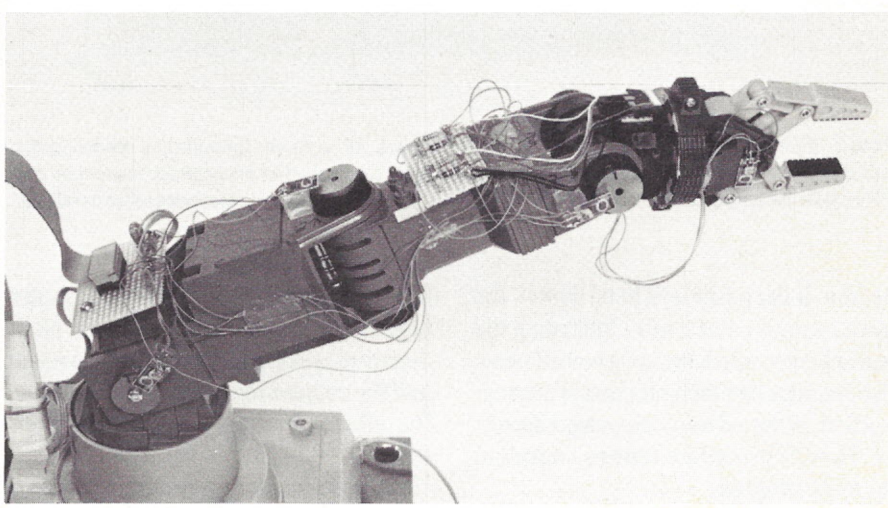


Photo 4. Hall-effect sensors and round magnets are carefully positioned so that each joint location provides a unique output voltage from the Hall-effect transducer. This goal required that the magnets be positioned so that the sensor never passes over either pole. This was achieved on all joints except the waist. Two optical encoders are used to sense wrist roll position. The two sets of alternating black and white patterns provide directional information and 32 positions per revolution.

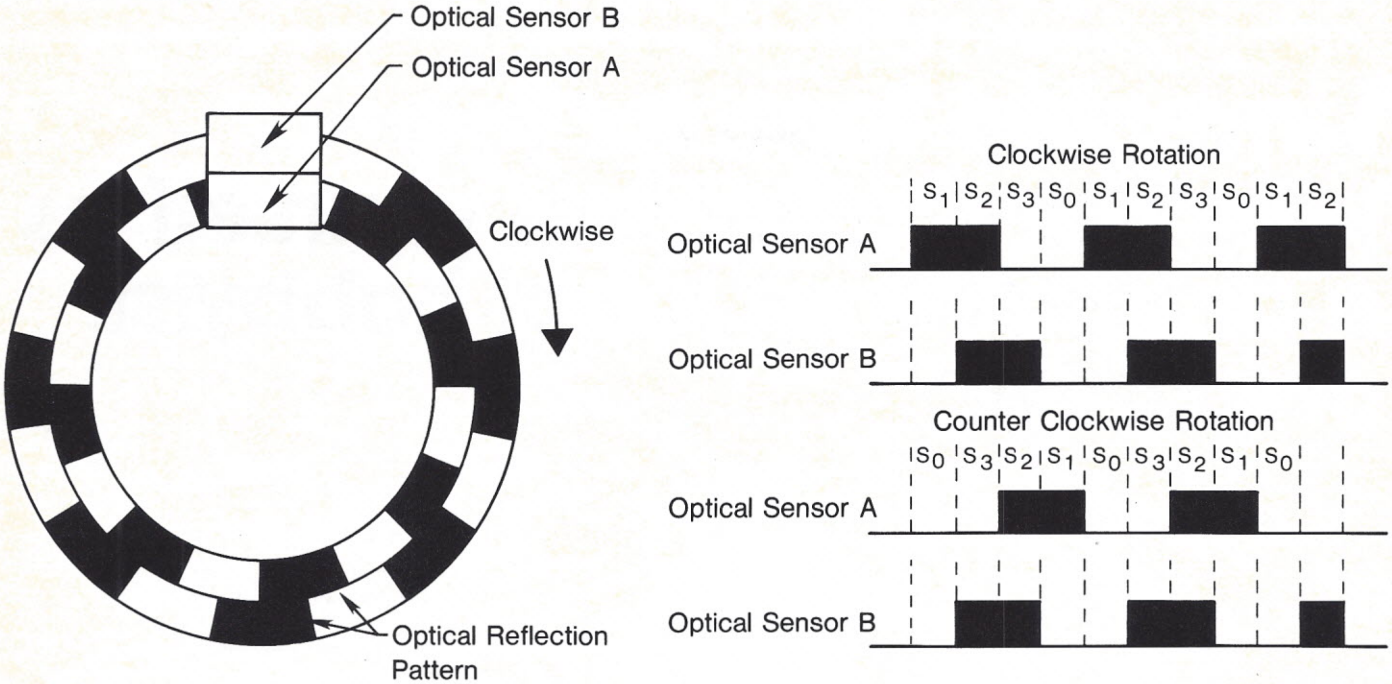


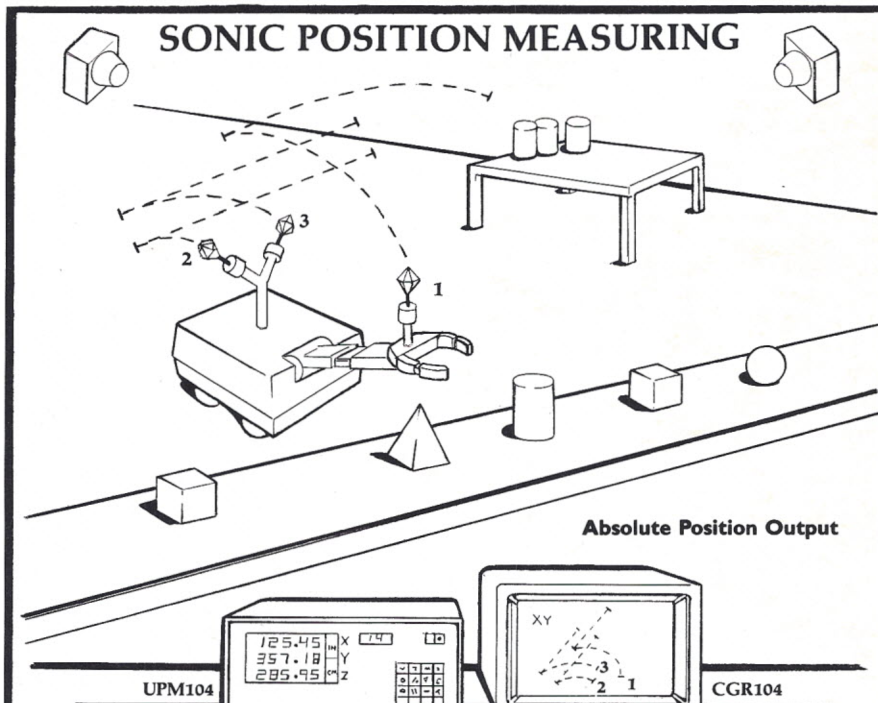
Figure 3. The optical reflection pattern on the disk causes the phototransistors in the light sensors to turn on and off. By using two sensors and offset reflection patterns, the outputs form four states. Clockwise rotation provides a count-up sequence, and counterclockwise rotation provides a count-down sequence. Because these sensors do not provide absolute position information, the state changes and direction of change are required to determine an absolute position.

magnet, yet requires reasonable positioning accuracy. We decided to use an optical shaft encoding technique for position sensing. We made a round paper ring to fit on the back rotating surface of the gripper assembly, as shown in photo 4. The paper is colored as shown in figure 3. The two concentric rings, each divided into 16 equal sectors alternating black and white, are offset by half a sector. Two TRW reflective object sensors (part number OBP 125A) were glued together, mounted on the pitch link, and aimed at the black and white disk, as shown in figure 4.

The sensors provide an electrical signal from a phototransistor which is amplified and made TTL compatible by using a Quad Norton amplifier (National Semiconductor part number LM 3900) as shown in figure 5. Although this signal can be fed into a parallel input port on a computer, we used two input channels on the already available analog-to-digital converter to read this data.

This shaft-encoding technique provides only relative position information. It provides for measuring direction of rotation in discrete increments of 11.25 degrees. Ab-

Continued on page 28



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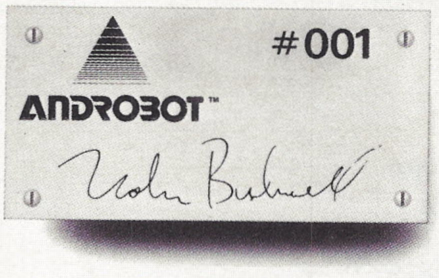

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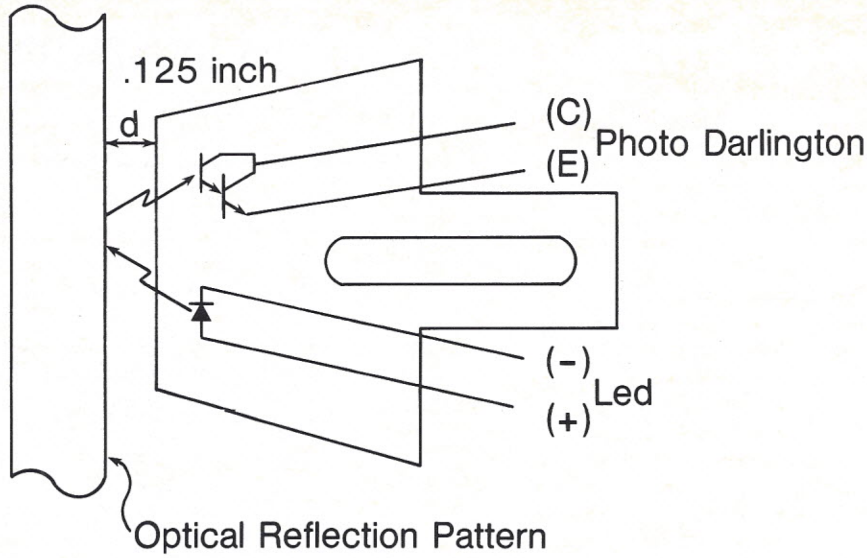

Figure 4. The optical sensor contains a light emitting diode (LED) and a phototransistor. A reflective surface causes the phototransistor to turn on, a light absorbing surface turns the phototransistor off. Shielding from external light sources is required to prevent 60 cycle interference.

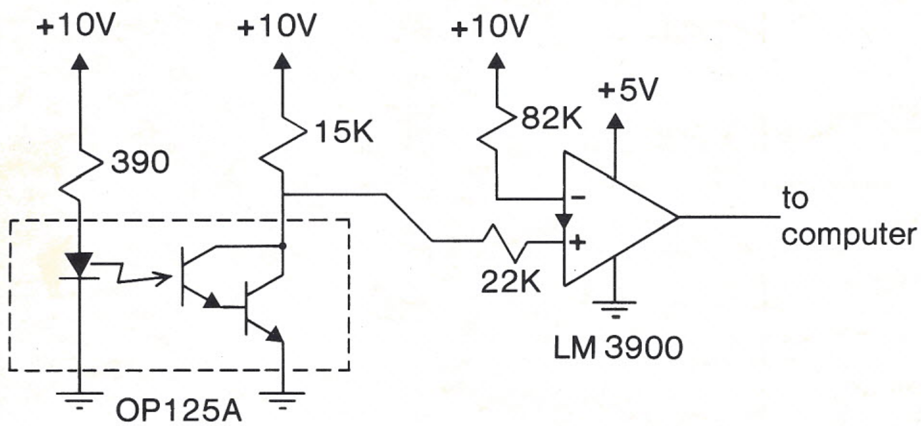

Figure 5. The photodarlington in the light sensor turns on when sufficient light is reflected from the LED. This brings the collector output to about 1V. Current flow into the negative input of the Norton amplifier is greater than the current flow in the positive input, resulting in a digital 0 output. When the LED is blocked, the photodarlington turns off, and the current flow into the positive input of the amplifier is greater than the negative input, causing the amplifier output to be a digital 1.

Continued from page 25

solute position is maintained in the computer by starting at the mechanical stop and accumulating positive and negative increments.

Sensing Gripper Position. The gripper also lacks a simple rotation point on which a round magnet could be placed. In this case, however, we felt it was not important to know the gripper's precise position as long as we could determine if the gripper was open or closed. We accomplished this by gluing a small bar magnet to the side of the upper section of the gripper and mounting a Hall-effect sensor, as shown in photo 4.

Power Supplies. Super Armatron requires two power supplies: +12V and +10V. The 10V supply powers the Hall-effect transducers and must be very stable. The 12V supply actuates the solenoids and is regulated with series regulators to also provide +5V for the logic circuits and +3V for the motor. Capacitive filtering and ferrite beads are used on the motor leads to suppress noise.

Conclusion. Although this robot arm only lift can three ounces, it provides an accurate microcomputer-controlled robot for experimentation. The Pascal program we developed is only a starting point. Super Armatron is capable of performing much more complicated tasks, including direct and indirect kinematics, and moving multiple joints at the same time. More importantly, the techniques used to construct and program Super Armatron can be applied to larger industrial robots. □

Acknowledgement.

We would like to acknowledge the support we received in this project from Joe Pollock, Gerald Wiles, and James A. Eicher. Eicher, a Wright State University graduate student, assisted in the development of software for the Armatron. Pollock and Wiles are Wright State University technicians who assisted in the electrical and mechanical design and fabrication of the modified Armatron.

The November/December 1982 issue of Robotics Age *contained an article describing Armatron, a plastic robot toy from Tomy which is currently being sold by Radio Shack stores.*

The November/December 1982 issue proposed a contest for "a significant enhancement to the use and control of the system." Super Armatron by John Schiavone, Mike Dawson, and James E. Brandeberry of Wright State University is the contest winner. This team won due to its extensive feedback controls, simple software control language, and system documentation. Special mention goes to Lyn Mercer and Tony Beckett, also of Wright State University, who used the same robot as an automated typist.

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John J. Schiavone received his BSEE in Computer Engineering from Wright State University in 1983. John is presently employed by The BDM Corporation. His specialties are microcomputer interfacing and networking. Dr. J.E. Brandeberry received his BSEE and MSEE degrees from the University of Toledo in 1961 and 1963, respectively, and his Ph.D. from Marquette University in 1969. He is currently an Associate Professor of Computer Science and Engineering at Wright State University. His interests are in electronics, computer hardware design, and robotics. Mike Dawson received his BSEE in Computer Engineering from Wright State in 1979. Mike is presently a systems software specialist with Digital Equipment Corporation.

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I wish to praise RI/SME for producing this much-needed directory and also thank Peter Blake of RI/SME for permission to extract this information. [rgac]

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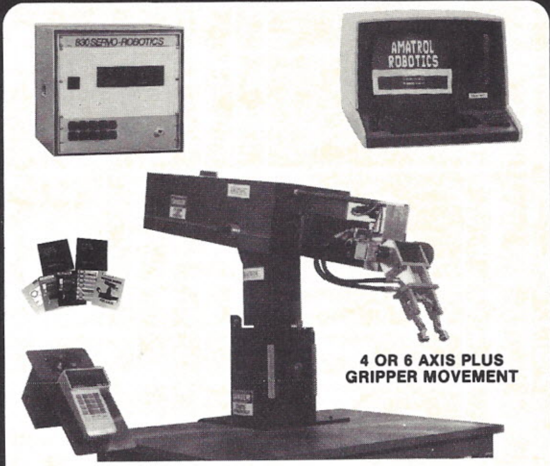

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Seiko Instruments, 700	✓		✓					✓	varies	✓				✓							✓	✓	
Sigma Sales, Sigma Max					✓				varies	✓			✓	✓			✓			✓	✓	✓	
Sterling Detroit, Robotarm	✓				✓				1000 steps	✓	✓	✓	✓	✓	✓				✓				
Systems Control, Smart-Arms	✓	✓				✓			200 steps/points														
Thermwood, Cartesian 5						✓													✓		✓		
Thermwood, Series Six	✓	✓					✓		3000 points								✓			✓			
Thermwood, Series Seven	✓	✓					✓		5 minutes	✓	✓		✓	✓									
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Tokico America, Spray-painting Robot						✓	✓		2800 points								✓						
Unimation, Unimate Apprentice									27 ft of weld									✓					
Unimation, Unimate Puma 250	✓	✓			✓	✓			500 points	✓									✓	✓	✓	✓	✓
Unimation, Unimate Puma 500/600	✓	✓			✓	✓			500 points	✓				✓				✓	✓	✓	✓	✓	✓
Unimation, Puma 760		✓			✓	✓			varies	✓				✓				✓		✓	✓	✓	
Unimation, Unimate 1000		✓				✓			Up to 256 points	✓	✓	✓	✓	✓	✓			✓					
Unimation, Unimate 2000		✓				✓			2048 points	✓	✓	✓	✓	✓	✓			✓					
Unimation, Unimate 4000		✓				✓			2048 points	✓	✓	✓	✓	✓	✓			✓					
Unimation, Unimate 8000		✓			✓	✓			varies	✓	✓	✓		✓	✓			✓					
Unimation, Unimate 9000		✓			✓	✓				✓	✓	✓		✓	✓			✓					
United States Robots, Maker 100	✓					✓			350 steps	✓	✓			✓						✓	✓	✓	
United Technologies, NIKO 150					✓				400 points	✓						✓		✓					
Westinghouse, Series 1000 & 2000										✓						✓					✓		
Westinghouse, Series 4000					✓	✓			1000 points				✓					✓				✓	
Westinghouse, Series 5000	✓	✓			✓				variable												✓	✓	
Westinghouse, Series 7000	✓	✓			✓	✓			800 points									✓					
Wexford Robotics					✓				1000 steps/points	✓					✓						✓	✓	
Yaskawa Electric, Motoman L3	✓	✓			✓	✓			2200 points	✓			✓	✓		✓		✓		✓	✓	✓	✓
Yaskawa Electric, Motoman L3C						✓			1000 points	✓			✓	✓				✓			✓	✓	
Yasakawa Electric, Motoman L-10G	✓	✓			✓	✓			2200 points	✓			✓	✓		✓		✓		✓	✓	✓	✓
Yasakawa Electric, Motoman S30	✓	✓			✓	✓			1000 points	✓			✓					✓					

Manufacturer, Model	Telephone	Typical Price	Load Carrying Capacity (lbf)	Repeatability (in)	Maximum Tip Speed, No Load (ips)	Coordinate System				Maximum Movement						Type of Drive			Control: Continuous Path, Controlled Path, Point-to-Point (C,C*,P)	
						Cartesian	Cylindrical	Spherical	General	Manipulator Reach	Manipulator Elevation	Manipulator Rotation or Translation	End Effector Pitch (deg)	End Effector Yaw (deg)	End Effector Roll (deg)	Electric	Hydraulic	Pneumatic	Non-servo	Servo
Seiko Instruments, 700	213/530-8777	$ 9,600	2.2	0.001	12		✓			7.9″	1.6″	120°			180			✓	P	
Sigma Sales, Sigma Max	714/974-0166	$ 4,000	1.	0.025	30			✓			90°	180°	90	180	180	✓				
Sterling Detroit, Robotarm	313/366-3500	$ 35,000	150	0.005			✓			120″	72″						✓			
Systems Control, Smart-Arms	617/263-1767	$ 4,000	4.4	0.02	90°											✓				
Thermwood, Cartesian 5	812/937-4476	$ 50,000		0.010						36″		60″					✓			
Thermwood, Series Six	812/937-4476	$ 50,000	18	0.125	40			✓		46″	80″	135°	180	180	270		✓			C
Thermwood, Series Seven	812/937-4476	$ 37,000	25	0.060						39″	76″	280°	180		300		✓			C
Thermwood, Series 3	812/937-4476	$ 35,000	50	0.06	45°			✓		60°	100°	280°	210		360		✓			P
Tokico America, Spray-painting Robot	213/328-7484	$100,000		0.080					✓	81″	89″	100°	210				✓			
Unimation, Unimate Apprentice	203/744-1800	$ 38,500	10	0.04				✓		64″	35″	64″	165	360		✓				
Unimation, Unimate Puma 250	203/744-1800	$ 41,000	2	0.002	39			✓		16″	29″	315°	240	535	575	✓				C, P
Unimation, Unimate Puma 500/600	203/744-1800	$41,000/ $47,000	5.5	0.004	20			✓		36″	62.5″	320°	200	532	300	✓				P
Unimation, Puma 760	203/744-1800	$ 60,000	22	0.008	40				✓			320°				✓				
Unimation, Unimate 1000	203/744-1800	$ 27,500	50	0.05	30			✓		42″	56°	208°	90	90			✓	✓		P
Unimation, Unimate 2000	203/744-1800	$ 46,000	300	0.05	30			✓		42″	56°	208°	220	200	360		✓			P
Unimation, Unimate 4000	203/744-1800	$ 64,000	450	0.08	36			✓		52″	51°	200°	226	320	370		✓			P
Unimation, Unimate 8000	203/744-1800	$ 52,000	300	0.05				✓								✓	✓			
Unimation, Unimate 9000	203/744-1800	$ 70,000	450	0.08				✓								✓	✓			
United States Robots, Maker 100	215/825-8550	$ 38,000	5	0.004	65			✓		20″	20″	350°	210	—	350	✓				C, P
United Technologies, NIKO 150	313/593-9600	$ 80,000	33	0.010					✓	53.3″	93″	320°				✓				
Westinghouse, Series 1000 & 2000	412/255-3329	$ 30,000	11	0.001					✓			360°				✓				
Westinghouse, Series 4000	412/255-3329	$ 65,000	22	0.008	3.9	✓						370°				✓				
Westinghouse, Series 5000	412/255-3329	$115,000	22	0.004	20	✓										✓				
Westinghouse, Series 7000	412/255-3329	$115,000	20	0.016	9.6	✓										✓				
Wexford Robotics	306/522-7429	$ 20,000	50	0.02	39.4											✓				
Yaskawa Electric, Motoman L3	312/564-0770	$ 50,200	6.6	0.004	70		✓		✓	40″	51″	240°	180		360	✓				C, P
Yaskawa Electric, Motoman L3C	312/564-0770	$ 71,000	6.6	0.004					✓	36.2″	47.8″	240°				✓				✓
Yaskawa Electric, Motoman L-10G	312/564-0770	$ 59,000	22	0.008	40		✓		✓	50″	68″	240°	180		360	✓				C, P
Yaskawa Electric, Motoman S30	312/564-0770	$ 45,200	66	0.012	40				✓	38″	30″	40″	—	—	—	✓				P

These tables are reproduced from the Stock Drive Products Data Book, Volume 2 available at $7.95 from: Educational Products, P.O.Box 606, Mineola, New York 11501.

This material is authored by Bernard Roth, a professor in the Design Division of the Mechanical Engineering Department at Stanford University in Stanford, California.

Patent Probe

New Robot Patent Category

Susan B. Rifkin
1401 South George Mason Drive
Arlington, Virginia 22204

Are you a stock exchange analyst who wants to know which corporation designs the most innovative tactile sensors?

Or perhaps you are an R&D planner who needs to know which control systems the competition is developing?

Maybe you are a robotics experimenter looking for a gripper for the robot you are building in your basement?

If you answered "yes" to any of these questions, you should know that United States patents contain information that can help answer these and many other questions.

United States Patent [19]
Engelberger et al.

[11] **4,260,941**
[45] **Apr. 7, 1981**

[54] **PROGRAMMABLE AUTOMATIC ASSEMBLY SYSTEM**

[75] Inventors: **Joseph F. Engelberger**, Newtown; **Torsten H. Lindbom**, Brookfield; **Maurice J. Dunne**, Newtown; **William Perzley**, Weston; **Wilbur N. Roberts**, Newtown; **Horace L. Gardner**, Ridgefield, all of Conn.

[73] Assignee: **Unimation, Inc.**, Danbury, Conn.

[21] Appl. No.: **31,462**

[22] Filed: **Apr. 19, 1979**

Related U.S. Application Data

[62] Division of Ser. No. 625,932, Oct. 28, 1975, Pat. No. 4,163,183.

[51] **Int. Cl.**[3] **G05B 11/32**
[52] **U.S. Cl.** **318/562**; 318/568; 415/5
[58] **Field of Search** 318/562, 568; 414/5

[56] **References Cited**

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FOREIGN PATENT DOCUMENTS

1418710 12/1975 United Kingdom 318/568

Primary Examiner—Gene Z. Rubinson
Assistant Examiner—Eugene S. Indyk
Attorney, Agent, or Firm—Mason, Kolehmainen, Rathburn & Wyss

[57] **ABSTRACT**

A programmable automatic assembly system is provided which may be employed to assemble small parts. Each assembly station includes cooperating manipulator arms which are programmable to assemble parts on a centrally located work table. Improved facilities are provided for teaching the manipulator arms at each station, these facilities including a computer which assists the teaching operator in setting up the programs required for assembly of small parts to close tolerances. Each manipulator arm includes closed loop teach facilities for maintaining the arm at a previously located position during the teaching mode of operation. The computer is employed as a teach assist facility in performing a number of tasks during the teaching operation which are extremely difficult for the operator to perform manually. All of the assembly stations may be controlled during playback from a common disc storage facility so that the control circuitry and memory storage facilities at each manipulator are minimized.

5 Claims, 73 Drawing Figures

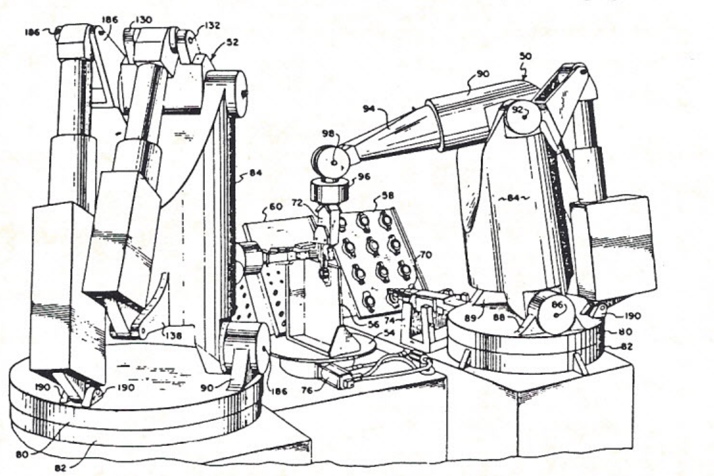

Figure 1. The front page of a patent names the inventors and assignees, presents an abstract of the patent, and provides a drawing of the invention.

Patent Contents. A patent's primary purpose is to protect inventors' rights to ideas and make technical information available to others. The front page of recent U.S. patents contain other valuable information. A typical front page is shown in figure 1. A patent's front page can tell you:

- Who the inventors are in an area of technology
- Where the inventors are located
- What organization, if any, was assigned the patent rights
- When the U.S. Patent and Trademark Office received the patent application
- What prior art is closely related to the invention protected by the patent
- A brief abstract of the technical disclosure in the patent
- A representative drawing

The first page of the specification usually includes a discussion of the prior art over which the patented invention is an improvement. The inventor often discusses the invention's goal and the approach he or she used to achieve that end. Succeeding pages discuss the invention and contain illustrative drawings. The specification concludes with one or more claims which point out and distinctly claim the subject the inventor regards as the invention or discovery. These claims sometimes are neither simple nor straightforward, but still are informative.

Obtaining Patents. Until recently, it was often difficult to obtain robot patents. Robot patents are categorized in many places, depending on the disclosed invention's structure. The Patent and Trademark Office has granted more than 4 million U.S. patents, which are categorized among approximately 113,000 divisions of technology that make up the U.S. Patent Classification System. One copy of each patent is kept in each appropriate division of technology.

Along with similarly categorized foreign patents and other technical publications, they make up a collection of over 25 million documents. Patents are placed into a category according to the structure of the inventions's technology.

A report produced by the Patent and Trademark Office for the National Technical Information Service lists 212 of the robot patents. This report, *Industrial Robots—A Survey of Foreign and Domestic U.S. Patents*, analyzes robot patents granted by the Patent and Trademark Office between January 1969 and March 1982. Although a good starting point, the report is not an exhaustive collection. Keyword searches on commercial automated patent data bases help to find some, but not all, robot patents.

Relief is in sight. The Patent and Trademark Office is establishing a collection of robot patents and technical literature. Class 901—Robots should be available in early 1984. This class contains 710 U.S. robot patents, about 1000 foreign patents, and 450 articles organized into appropriate categories.

Officially, this classification is a "cross-reference art collection." The patents in it can still be found under other classes. Class 901 is a collection of patents whose primary or original classifications are in another area of technology. In Class 901—Robots patents are categorized into such technologies as:

- Arm motion controllers
- Programming systems
- Arm movement coordinate systems
- Manipulator arm parts
- Drive systems
- Means for communicating with other machines
- End effectors
- Sensing devices
- Safety devices for robots

The Patent and Trademark Office has also collected foreign patents and non-patent literature. Copies of the foreign patents and technical articles are being placed into appropriate categories in Class 901. This means that the U.S. patents, foreign patents, and technical articles will be in a "search room" at the Patent and Trademark Office, where they will be available for perusal. Pertinent books, along with extensive bibliographies, are available in the Patent and Trademark Office Scientific Library.

The information is also located in the more than 40 Patent Depository Libraries

Alabama	Auburn University Library	(205) 826-4500, X21
	Birmingham Public Library	(205) 254-2555
Arizona	Tempe: Science Library, Arizona State University	(602) 965-7140
California	Los Angeles Public Library	(213) 626-7555, X273
	Sacramento: California State Library	(916) 322-4572
	Sunnyvale: Patent Information Clearinghouse	(408) 738-5580
Colorado	Denver Public Library	(303) 571-2122
Delaware	Newark: University of Delaware	(302) 738-2238
Georgia	Atlanta: Price Gilbert Memorial Library, Georgia Institute of Technology	(404) 894-4508
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	St. Louis Public Library	(314) 241-2288, X390,X391
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Oklahoma	Stillwater: Oklahoma State University Library	(405) 624-6546
Pennsylvania	Cambridge Springs: Alliance College Library	(814) 398-2098
	Philadelphia: Franklin Institute Library	(215) 448-1321
	Pittsburgh: Carnegie Library of Pittsburgh	(412) 622-3138
	University Park: Pattee Library, Pennsylvania State University	(814) 865-4861
Rhode Island	Providence Public Library	(401) 521-7722, X226
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	Houston: The Fondren Library, Rice University	(713) 527-8101, X2587
Washington	Seattle: Engineering Library, University of Washington	(206) 543-0740
Wisconsin	Madison: Kurt F. Wendt Engineering Library, University of Wisconsin	(608) 262-6845
	Milwaukee Public Library	(414) 278-3043

Table 1. These libraries offer CASSIS (Classification And Search Support Information System), which provides direct, on-line access to Patent and Trademark Office data. The information contained in the Sunnyvale California Patent Information Clearinghouse is organized by subject matter. The phone number listed for the Franklin Institute Library in Philadelphia, PA should be used only between the hours of 10:00 AM and 5:00 PM.

(see table 1). These libraries receive current issues of US patents and maintain collections of earlier issued patents. The scope of these collections varies from library to library. Many of these libraries have complete collections dating back to 1790. All libraries, except one, offer CASSIS (Classification And Search Support Information System). CASSIS provides direct, on-line access to Patent and Trademark Office data, including keyword search capability.

The Robots classification will be available on the CASSIS system as soon as the class is officially established. You will be able to use the following method to find specific types of robot patents:

- Select the *Manual of Classification* page that contains the official "schedule" (list of categories)
- Choose a technology category and note its classification number
- Ask CASSIS to display the patent numbers for all patents in that category
- CASSIS responds with a list showing the newest patents first
- After obtaining the list of patents, you can either look up the patents at the Patent Depository Library or order patent copies from the Patent and Trademark Office

Custom Reports. An alternative method of analyzing data from a large number of patents is available. The Patent and Trademark Office's Office of Technology Assessment and Forecast can provide custom reports generated from their computerized patent data base. The Office of Technology Assessment and Forecast provides a variety of reports analyzing such patent data as:

- Organizations assigned patents within a given technology
- Titles and numbers of patents within a given technology, or assigned to specific organizations
- The names and addresses of inventors of unassigned patents
- The field of search and references cited in the examination leading to the patent grant
- The year of patent application or grant
- The inventor's country of residence

The Office of Technology Assessment and Forecast provides these reports on a cost-reimbursable basis. Reports are available for any category of technology that can be identified under the U.S. Patent Classification System. After Class 901 is part of the system, you will be able to order these custom reports on robotics areas.

The process of developing Class 901—Robots will continue even after it becomes available for use. If you have any comments or suggestions, you can contact the Patent and Trademark Office. You may send comments about the class organization to Mr. Edward J. Earls, Director, Mechanical Classification. The Patent and Trademark Office will also appreciate referrals to organizations with information to add to this collection. Ms. Joan Mavity of the Patent and Trademark Office Scientific Library is in charge of collecting nonpatent literature. □

Patents may be ordered from the Patent and Trademark Office, Department of Commerce, Washington, DC 20231. The cost is $1.00 per patent request.

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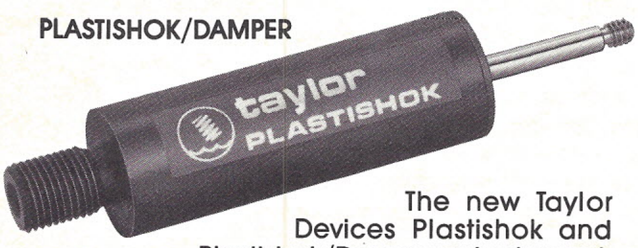
PLASTISHOK/DAMPER



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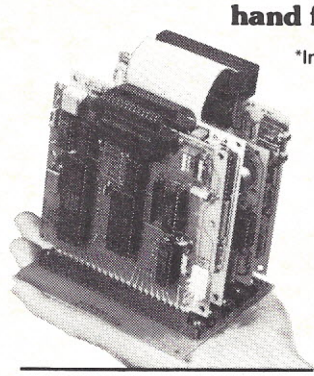

As featured in Ciarcia's Circuit Cellar, Byte Magazine, July, August, 1981.

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Operator Roles in Robotics

John Lyman
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and

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Progress in hardware, software, sensory technologies, and artificial intelligence methodologies has made robotics a solution to problems in industrial, medical, and battlefield applications. The principal function of robotics in each of these applications is to replace, augment, aid, and improve human performance in sensory, manipulative, and cognitive functions.

Today's complex tasks, however, still require humans to supervise the robot's operation, to control its performance, and to monitor its status. The roles of the human operator have a significant impact on the human-factors aspects of robotic systems design. New, unanticipated operator roles can evolve in response to significant advances in machine intelligence. The role of the human operator in robotics and the associated human-factors problems are described in this article.

Background. Automation has already made its mark in industry and commerce. In its earliest widespread applications (during the 1950s and 1960s), the human operator served as watchman, repairman, bookkeeper, or activator. In such applications, however, robotics and automation consisted of closed-loop control devices that did not require human intervention.

The next generation of automation, from 1970 to 1979, used developments in computer technology, large-scale integrated circuits, sensors, and machine decision making to construct robots that assumed some of the human's low-level decision-making responsibilities. In these systems, the task was defined a priori, but the specific sequence of the task execution was not known in advance. As a result, on-line decision making beyond a simple go or no-go decision was typically required.

In the 1980s, the focus of robotics research has shifted to developing intelligent systems capable of performing with the human operator in the higher-level cognitive functions. The goal of these systems is to cope with unstructured and uncertain environments during the performance of their tasks. Expert systems technology is expected to be used to increase the problem-solving and decision-making abilities of these intelligent robots. (For more information on the current state of knowledge in the robotics field, see the references at the end of this article.)

Robotic systems are unique in that they cannot be readily classified as manned or unmanned according to current standards. A robotic system that has no human aboard, for example, may still be controlled by an operator from a remote site. If "manned" implies an onboard operator, a remote system would be classified as unmanned. However, since a human operator is monitoring and supervising its behavior from a remote location, it may just as well be termed manned.

We define a robotic system as a man-machine system that replaces, enhances, and extends human sensory, manipulative, and cognitive capabilities. The purpose of a manipulative system, for example, may be to enable the human to grasp objects and work at locations where the environment is unsafe for humans, where the task requires capabilities beyond human endurance or strength, or where the environment's spatial constraints (such as a cramped area) prevent human presence. Similarly, the purpose of a sensor system may be to locate objects in poor visibility conditions.

Operator roles. The primary roles of the robot operator fall under three general categories: monitor, manager, and main-

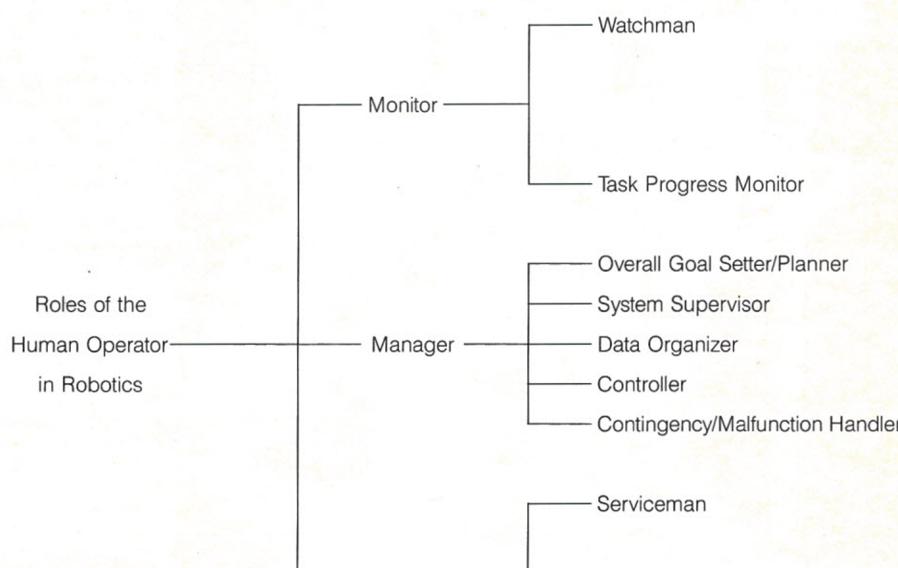


Figure 1. The role of the human operator in robotics.

tainer. The monitor checks the status of subsystems and overrides the system on occasions when the task is not progressing satisfactorily.

The manager's role includes setting goals, making decisions, supervising subsystems, organizing data, controlling the system, and handling contingencies. When planning and setting goals, the manager is operating at the most abstract level in the task-performance hierarchy. At this level, the scope of his or her knowledge requires more breadth than depth. As system supervisor, the manager sets schedules, determines task assignments, monitors the progress of the task, and intervenes when necessary to exercise override options. These options could include narrowing the scope of the task, revising interim goals, reallocating assignments, or aborting the mission.

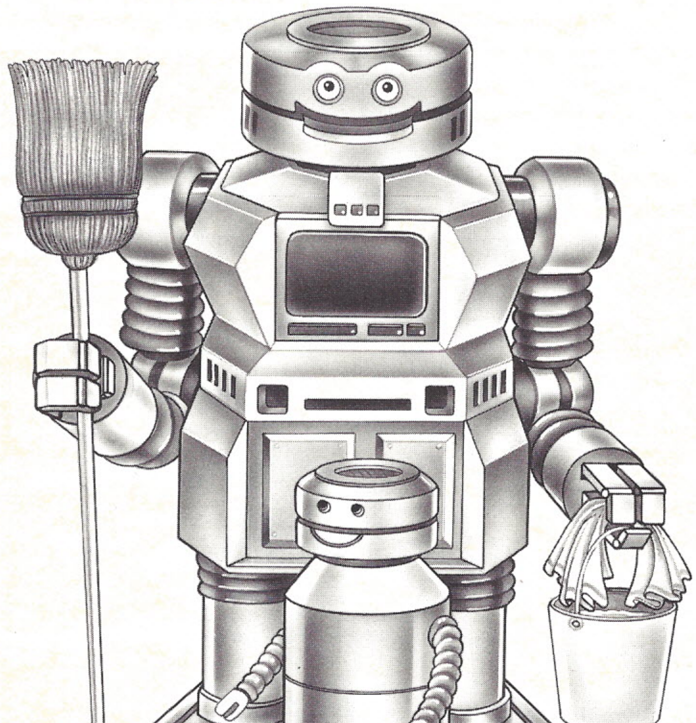
As a data organizer, the manager assimilates, arranges, generates, and filters information. The manager's burden depends on the complexity and volume of the data to be organized, on the time constraints that he or she must perform under, and on the availability of effective information-management aids. In the manager's controller capacity, he or she specifies the command to be executed by the system, evaluates the system's response, and issues a new command.

Finally, as a contingency handler, the manager has two key duties—to anticipate abnormal situations and to cope with malfunctions when they occur. In both cases, the manager must understand the types of problems that could arise, and must be able to develop and implement contingency plans. Since the first contingency plan may not always work, the manager must also be able to make on-the-spot plan revisions.

In the maintainer's role, the robot operator is concerned with identifying and diagnosing problems and with performing preventive and corrective maintenance. Fully self-maintaining robots and specialized maintenance robots are some time away, although increasingly sophisticated, built-in, diagnostic displays will make the maintenance role more routine.

Human factors. Each operator role has its own information-processing and decision-making demands, or task burdens. The monitor's task burden is the least taxing, with relatively few decision-making occasions, most of which are reasonably well defined. The manager's workload is usually significant and sometimes too high to expect acceptable performance for any length of time. Different decision-making opportunities, from simple to complex, arise under each of the manager's subroles. The maintainer's burden varies with the type of maintenance he or she performs. With preventive maintenance, the operator's workload is generally predetermined and usually reasonable for performing routine maintenance tasks, corrective maintenance, or troubleshooting. The workload and the task complexity could impose excessive pressures, especially if the process requires real-time response.

Identifying human-factors problems. The monitor-manager-maintainer frame provides a convenient basis for identifying critical human-factors problems. From the operator standpoint, these problems include: employing effective learning approaches to increase operator expertise; identifying appropriate skill requirements and task burdens; assessing human performance capabilities against task require-



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Circle 22

ments; assigning tasks to the operator on the basis of suitable criteria; assuring health and safety.

From the technological standpoint, the robotic system must: perform reliably within the environment and task constraints for which it was designed; be able to communicate relevant status and sensory information to the operator in each of his or her capacities as monitor, manager, or maintainer; be able to justify its existence as a cost-effective replacement for a human worker.

Additional human-factors problems include assessing the capability of both the trained and untrained operator, and predicting reliably how well an operator will perform in unanticipated situations. The latter problem is significantly more difficult.

Familiarity with a situation is yet another variable with human-factors ramifications. The robot-human relationship during routine situations tends to be highly structured. It is easier to predict how well an operator will perform when the system is fully specified than when he or she is working in an unstructured environment.

In highly structured environments, autonomous operation by a priori scheduling is favored over human scheduling decisions. The success of the United States' unmanned space-exploration program demonstrates this. Usually an autonomous robot operates subject to go/no-go operator decisions, a mode that might be termed "acknowledgement-consent." A common variant of this mode occurs when the operator directly initiates operations which then become autonomous. The inevitable problem that confronts such systems is that the communication link between the operator and the robot may be broken, with no recovery possible. As task complexity and environmental demands increase, the tradeoff between the role of human intelligence and the adaptive capabilities of the robot system becomes more complex. At an extreme, the operator's creative abilities are pressed to their limits.

This leads us to the root of what is perhaps the most difficult human-factors problem: dividing responsibilities between the operator and the robot within the current technological constraints. This problem can be addressed by breaking down the task into its functional components, and making tradeoffs where possible. These components include:

- sensory modes and levels of stimulation
- data storage
- knowledge encoding and transfer
- programming capability
- operations in failure mode
- adaptability to multiple operation
- span of control by one operator
- endurance limits

Ideally, task allocation should be situation adaptive; that is, responsibilities of the operator and robot should shift in response to changing demands—a true teamwork approach. This concept includes responsibility exchanges at any of the major input, throughput, or output subtasks. The degree of true teamwork achievable today is hampered by computer memory and processing limitations, and by the state of the distributed processing, artificial intelligence, sensor, and computer networking technologies.

Finally, the physical and mental burdens imposed on an operator by the need to interact with a robotic system must always be carefully defined in terms of safety and endurance. A highly system-specific analysis is required for this aspect of human role assessment.

Conclusion. We have suggested that operator roles in robotics can be classified under the categories of monitor, manager, and maintainer. With increasingly sophisticated applications of machine intelligence, however, these roles will require explicit and continuing reassessment. □

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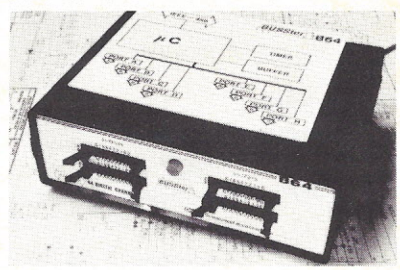

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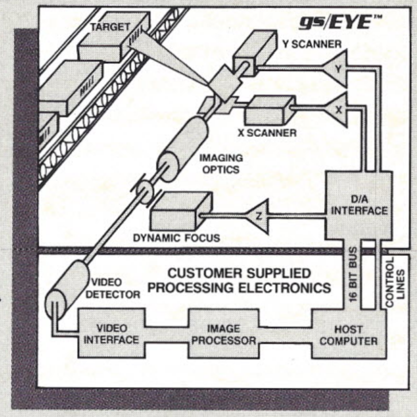

The gs/EYE provides an expanded field of view for existing or planned robotic vision systems. It eliminates the need for stationary, multiple cameras or cumbersome mechanical methods for random access. The gs/EYE is a programmable work station which is software controlled from the host computer. In industrial settings, this software control provides maximum operational flexibility and minimizes re-configuration set-up time.

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The Scorpion
SOFTWARE OVERVIEW

Harprit S. Sandhu
2505 South Neil Street
Champaign, Illinois 61820

When designing a product, it is necessary to make a number of decisions that are transparent to the final user. Since the Rhino Scorpion is intended as a sophisticated and expandable floor mobile robot, certain criteria had to be kept in mind at all times. Of these, price and performance are the obvious prime considerations, but there are many others of interest to the robot enthusiast.

Since a robot interacts with its environment, we emphasized sensory and environmental controls; the input and output for the robot. In order to have good I/O control, we must select a good I/O chip. One of the best-known sophisticated I/O chips is the 6522. Two 6522s provide 32 I/O lines and four counter/timers. The Scorpion provides expansion room for a third if needed. Now, what can be done with these 32 lines?

First let's consider the floor over which the robot runs. Floors are usually flat, but they can have patterns. If we could detect changes in brightness, we could find and follow edges. However, to really explore the floor, the robot needs two detectors. At this point we have used up a total of three of the 32 I/O lines. One is used to turn on lights to illuminate the floor, and two are used to monitor the resultant brightness.

To create an interesting device, the Scorpion should be capable of making noises. One I/O line is used to control a speaker. For starters, we provide the ability to control the tone and its duration, using two of the timers on the 6522s. We have now used a total of four I/O lines and two timers.

As the robot runs about, it will undoubtedly run into obstructions. To make intelligent decisions, we must determine which part of the robot encountered an obstruction. This will require a minimum of four switches to identify left, right, front, and back collisions. To provide even finer resolution, we can use eight switches (two on each side) to detect left-front, right-rear, etc. This scheme uses up another 8 control lines.

Of course, the robot must move. This motion requires a minimum of two motors to control both speed and direction. We decided to use stepper motors which are each controlled by two control lines. In addition, wheel speed is controlled by using two more timers on the 6522.

We need additional sensory information in addition to the bumper sensors. Vision would be an ideal addition. Unfortunately, conventional vision systems are too expensive. What if we could build an optical scanner that scanned the environment, collected the information, and displayed the information on the video screen? A display of 40 characters by 25 lines would produce 1000 pixels of varying brightness. This should be sufficient for recognizing many simple objects. We could experiment with pattern recognition, perform calculations to enhance contrast, and find edges.

To gather this information, a cadmium/sulfide (CdS) photosensor is mounted at the focal point of a solar cigarette lighter and connected to an oscillator. As the assembly

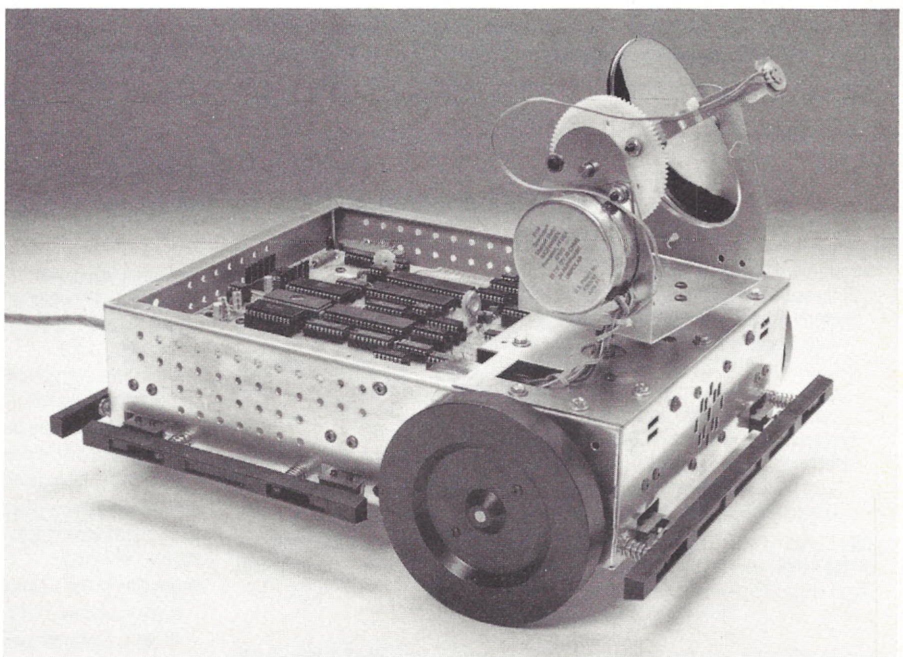

Photo 1. A fully-assembled Scorpion with the cover removed to expose the computer control card. The 0.5 inch on-center holes along the sides and rear of the Scorpion can be used to attach Meccano and Erector set components to the system. The two microswitches behind each bumper and the two-axis optical scanner help form a rugged and reliable robot suitable for experimentation in artificial intelligence and robotic programming. The robot sells in kit form for $660.

About the Author:
Harprit S. Sandhu is the President of Rhino Robots, PO Box 4010, 3402 North Mattis, Champaign, Illinois 61820

INSTRUCTION	MEANING OR PURPOSE
/7M + ## – ##	Start both drive motors
/4L – ##	Start left drive motor
/4R + ##	Start right motor
/2HR	Reset horizontal scanner
/5HM – ##	Move horizontal scanner
/4HS##	Do a horizontal scan
/2VR	Reset vertical scanner
/5VM – ##	Move vertical scanner
/4VS##	Do a vertical scan
/2E#	Control the eyes
/2G#	Control ground tracker lamps
/5Sffdd	Control speaker frequency and duration
/7Waaaa##hhhh....	Write programmable memory locations
/7Raaaa##	Read memory locations
/1R	Reset the system
/3Yhh	Set I/O master byte
/3Zhh	Ignore/Obey the I/O master byte
/8C + ######	Move left motor a specific amount
/8D + ######	Move right motor a specific amount

INSTRUCTIONS THAT HAVE ANSWERS

QUESTION	MEANING,USE	ANSWER
/1B	Bumper status	Bhh
/1S	Scanner data	SHhhhhhh..
/1E	Eye status	E#
/1G	Ground lamp status	G#
/1T	Tracker status	T###
/1M	Motor move status	M – #### + ####
/7Raaaa##	Read memory	Rhhhhhh..
/1Y	Read I/O byte	Yhh
/1X	Read busy byte	Xhh
/1C	Left motor steps to go	C####
/1D	Right motor steps to go	D####
/1P	All parameters	PBhhE#G#T###M – #### + ####
	parameters continued	YhhXhhC####D####

Table 1. Instruction set for Scorpion operating system. All questions are answered and terminated with hexadecimal 0D0D0A. In the instruction set definitions, the following conventions are used: # = single decimal digit; hh = two-digit hexadecimal value between 00 and FF; aaaa = a hexadecimal digit between 0000 and FFFF.

scans the room, the oscillator varies from 13 Hz up to 1300 Hz. The Scorpion control board dedicates eight bits to reading a digital counter and another bit to resetting the counter. Two more motors are used to control the horizontal and vertical scans.

We have now used up a total of 29 bits. Adding two phototransistor eyes uses up two of the last three bits. The last available control bit is used to control the motor power so that we can shut them off completely. This saves a lot of power when we are using batteries and also allows us to turn off the four main motors and turn on the two optional motors without needing more power.

Software Control. One of the problems encountered when designing a small system is the temptation to make the system do everything imaginable. Unfortunately, in a small system, this usually means nothing is developed very well. The ideal is to design a spartan but clever system that the user can modify. Flexibility is the foremost target.

Since part of the Scorpion's operating system is in EPROM, we moved all system constants to programmable memory so they can be modified. This allows you to extend and change the operating system without having to create new EPROMs.

The operating system looks at the programmable memory four times: after system housekeeping, after processing all the system-defined instructions, before the interrupt routine, and at the end of the inter-

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Axis Two: Shoulder is powered thru 105°. The motion you use doing jumping jacks.

Axis Three: Upper arm is powered thru 135° of rotation. The motion you use while arm wrestling.

Axis Four: Elbow is powered thru 115°.

Axis Five: Wrist is powered thru 90°.

Axis Six: Gripper opens up to 2½ inches and closes down to zero.

All arm servos are powerful enough to enable 'MARVIN' handling a minimum five pounds load in each gripper. (A six pack of your favorite beverage weighs approx. 4½ lbs.)

In addition to the 12 arm axes, 'MARVIN' has:

Neck is powered thru 180° rotation.

Waist is powered from straight up to 50° forward. This enables him to reach the floor with his grippers.

Drive Wheels- Each drive wheel is an individual servo to enable directional control. His maximum rate of forward speed is 50 inches per second and he has enough power to climb a 10% incline.

Circle 24

rupt routine. You can add your own operating system and extend the system with your own instructions. You can also alter the interrupt routines.

A useful experimental system must be able to talk back to a host computer. Only then can you close the control loop and use powerful machine intelligence procedures. Don't ever overlook the necessity of feedback in any system.

Other Hardware Information. All ideas developed for and on the Scorpion are directly applicable to full-sized mobile robots, machine intelligence investigations, and pattern recognition studies and schemes. The Scorpion provides the hardware necessary to try out your ideas without requiring large amounts of money.

The two-axis optical scanner can discriminate between lights of varying brightness, and provides the ability to perform celestial navigation by assuming that a light bulb at the ceiling is the north star. A seven-bit counter allows the discrimination of up to 127 brightnesses. Adjustable sensitivity is provided. This scanner allows you to collect optical data. You can manipulate the data mathematically to increase contrast and discern edges, images, etc. Optical recognition strategies can be worked out. The scanner resolution is 1.5 degrees per step.

Control Instructions. Instructions are sent to the Scorpion by transmitting data to the port to which the robot is connected. The instruction format is as follows:

- The first byte is always a slash, "/." Whenever the Scorpion sees a "/," it resets the buffer and prepares to receive information.
- The next byte usually tells the Scorpion how many bytes of data to expect. Up to nine bytes of data transmitted in ASCII format can be accepted. A decimal "1" is transmitted as a hexadecimal 31.
- The data itself follows the number. The first byte after the "length of data" byte is an alphabetic character. This usually identifies the type of instruction being sent. The data is always in hexadecimal ASCII format.

Questions. The second set of instructions are *questions* that the Scorpion answers. For example, we can ask the Scorpion for the status of the two ground tracking phototransistors whenever we want. The question format is the same format used for instructions.

The *answers* given by the Scorpion can vary in length from 1 to 300 bytes. The answer format organization follows:

- The first byte identifies the type of information sent. It can be an alphabetic character like "E." In our case "E" represents the eyes.
- The data follows in hexadecimal ASCII format.
- All answer transmissions end in hexadecimal '0D0D0A', representing two carriage returns and a line feed. This can be changed to whatever you want. □

Next Month. *Next month's article, the second in this three part series about the new Scorpion robot, describes the first half of the instruction set in detail.*

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55	65	75
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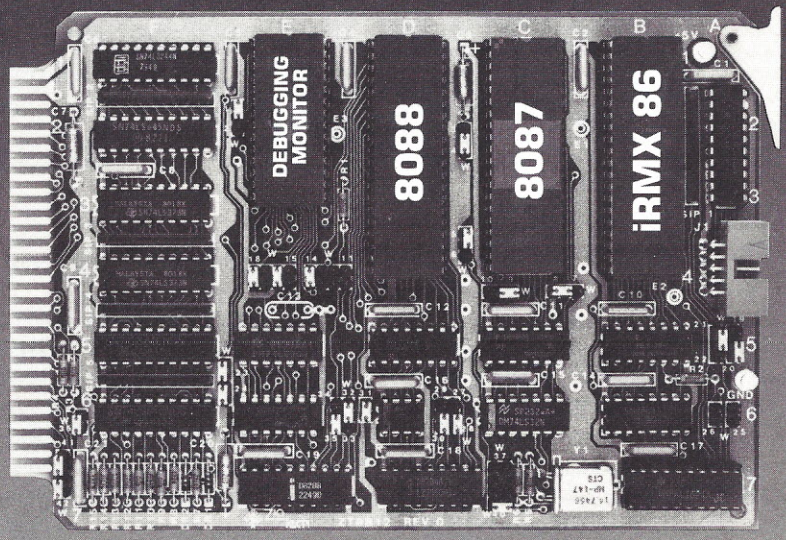

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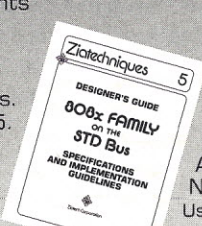

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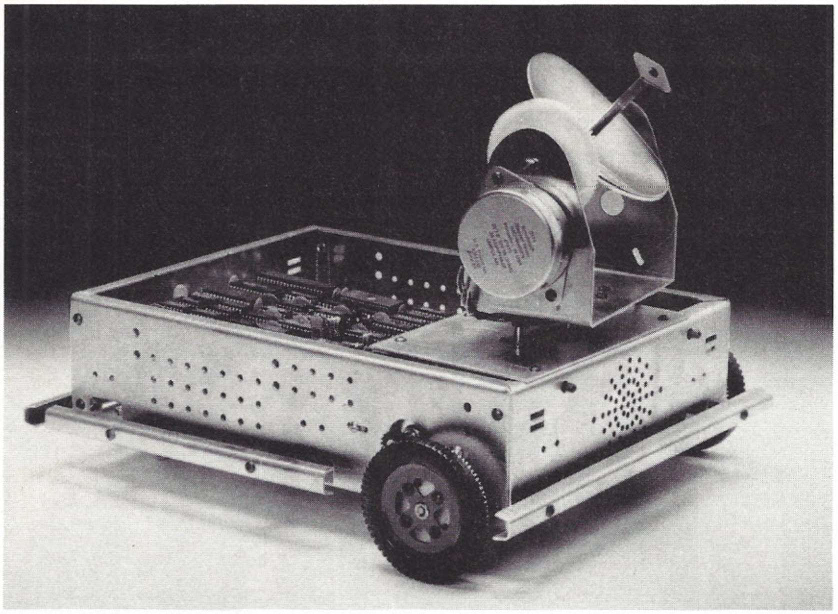
New Products



Rhino Scorpion

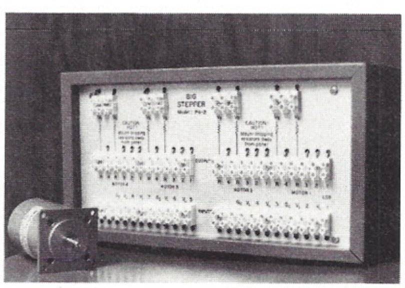
Rhino Robots has introduced the Scorpion, a small, sophisticated robot designed for the serious computer experimenter. The on-board 6502 computer and two 6522 interface chips are software controllable. The Scorpion is programmed via an RS-232C serial interface. The on-board computer contains 8K bytes of EPROM and 2K bytes of programmable memory which is expandable to 64K bytes. Detailed electronic, mechanical, and programming information is contained in the 130-page manual.

The Scorpion can follow a tape on the ground, and detect various bodies through touch sensors. A two-axis optical scanner can recognize patterns over a 300-degree scan in both vertical and horizontal planes, with resolution of 1.5 degrees of scan per step. Contact: Rhino Robots, Inc., PO Box 4010, Champaign, IL 61820. Phone: (217) 352-8485. Circle 40

Stepping Motor Driver Box

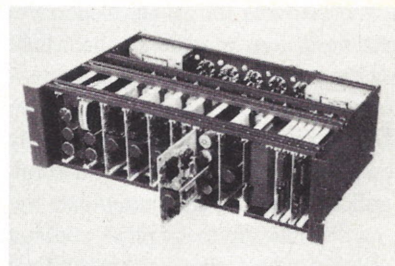
The Smart Stepper is a microprocessor-controlled stepping-motor driver. The product supplies all of the power and circuitry to drive four stepping motors. (Approximate motor size limit is 30V and 5A per winding.) The Smart Stepper is controlled via an RS-232 port. An on-board Z80A provides intermediate commands for controlling the number of steps, speed, direction, acceleration, half stepping, and many other functions. A built-in, time-of-day clock can be read from the controlling computer. Further control is possible with two opto-interruptors or limit switches per motor. Sample FORTRAN, BASIC, and assembler programs are included.

The Smart Stepper is available for $850 from Centre Computer Consultants, PO Box 739, State College, PA 16801. (814) 237-4535. Circle 42



Robot Controls

The Robotic Development System features a full line of plug-in electronic/pneumatic modules with STD-Bus compatibility. The system is capable of controlling and monitoring any combination of 32 pneumatic valves, pressure switches, transducers, or other elements. For a copy of their 16-page catalog, write: Robitech, Inc., Philip A. Surette, Director of Marketing, 134 Mystic Avenue, Medford, MA 02155. (617) 395-3633. Circle 41

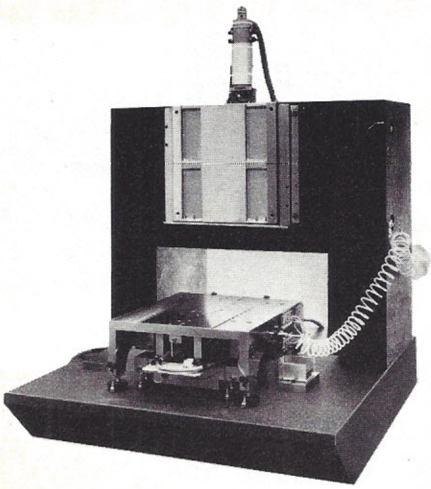


Smart Rabbit

Hobby Robot Co. has introduced the Smart Rabbit Robot, a personal robot that stands just under 22 inches tall and weighs less than 25 pounds. The Smart Rabbit is designed and priced as an entry-level robot for young robotics enthusiasts, and is a useful educational tool. The robot can carry a Timex-Sinclair TMX-1000 computer for independent control or be controlled via most home computers.

The Smart Rabbit is available in two kits. Level 1 includes a motorized base, head-mounted speaker, and eye LEDs, and a computer interface to allow control by either a Timex-Sinclair, Commodore VIC, or PET 2000/4000 via a parallel output port. The Level 2 Rabbit includes all Level 1 components, mother board, servocontrolled arms and grippers, servocontrolled head, and the necessary mechanical components to provide a computer-controllable robot with functioning arms, grippers, and head. All servomotors are proportionally controlled via the computer bus. Contact: Juanita M. Dodd, Hobby Robot Co., Inc., PO Box 887 Hazlehurst, GA 31539. (912) 375-7821. Circle 43

New Products



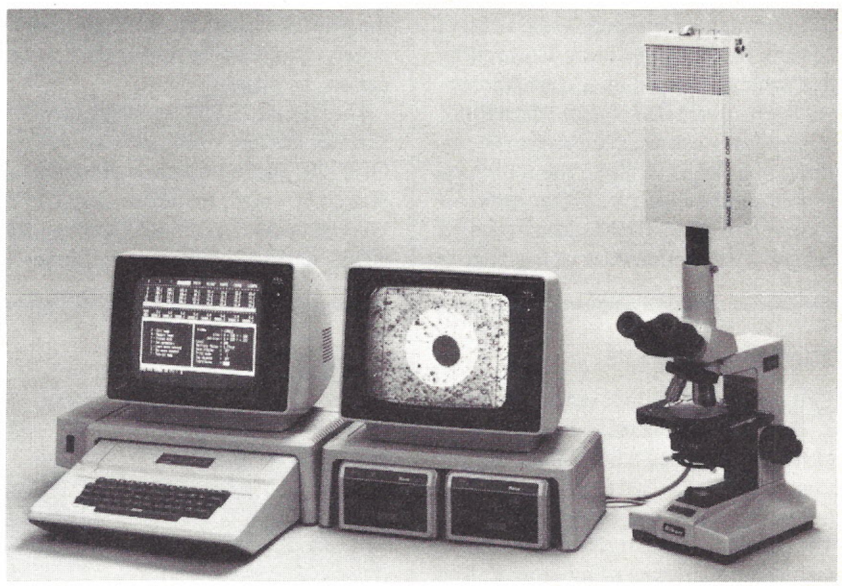
XYZ Positioning System

Anorad Corporation has introduced a high-speed, high-accuracy, air-bearing positioning system driven by linear motors. Possible applications include automatic inspection of semiconductor wafers, high-precision lithography, and automatic assembly. The X and Y axes are special air-bearing Meehanite carriages. Both bear and ride directly on a highly stable lapped granite base. This removes the weight of one table bearing on top of the other, eliminating resultant cantilever deflections. Contact: Martin Meyers, Anorad Corporation, 110 Oser Avenue, Hauppauge, NY 11788. (516) 231-1990. Circle 44

Image Analyzer

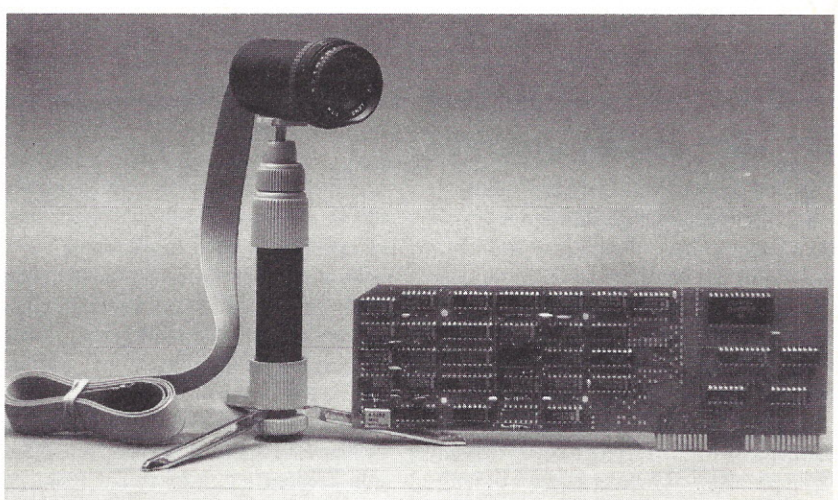
Image Technology Corporation has introduced the Model 2000 Image Analyzer, a computer-controlled, low-cost system designed for the researcher or engineer who requires measurements such as length, width, area, perimeter, shape, or position. The Model 2000 uses a video camera, video processor, and computer to provide noninvasive measurements accurate to 1/512 of the measurement field. Measurements can be made directly from a microscope or through a 50mm macroscopic lens.

All image analysis functions are controlled directly from the computer. The operator enters measurement commands from the keyboard which can be stored and executed at a later time. Typical applications include: detecting defects in silicon substrates, robotic control, microcircuit quality control, phase analysis of minerals, cell counting and sizing, and microscopic measurements. Contact: Image Technology, Corporation, 120 Jefryn Boulevard, Deer Park, NY 11729. Phone: (516) 595-1600. Circle 45



Micro D-CAM Image Sensor

Micromint's 256 by 128 silicon array array digital image sensor and menu-driven software allow your computer to interpret, enhance, and store images. Available in IBM PC and Apple II versions (RS-232 versions available on special request). Micro D-CAM software includes utilities for auto exposure, multilevel grayscale, screen dumps, picture storage, and image enhancement. Typical uses include graphics, pattern and character recognition, robotics, process control, and security. The assembled camera and interface card costs $295.00. For more information contact: The Micromint, Inc., 561 Willow Ave., Cedarhurst, NY 11516. (800) 645-3479. Circle 46

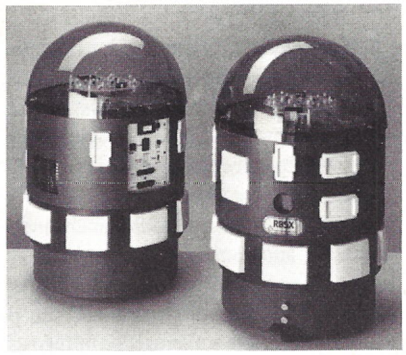


New Products

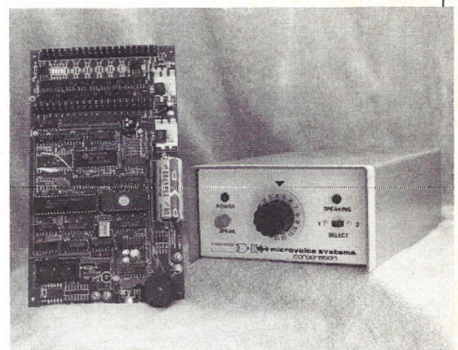
RB5X Enhancements

The RB5X comes completely assembled with Polaroid Rangefinder™ sonar sensing, its own battery charger, and circuitry and software that enables it to find its charger when the batteries are low. Hardware options, such as voice synthesis and a robotic arm, are available as add-ons. The most significant enhancement is on the interface panel. A socket has been added for connecting an optional 2K byte or 4K byte preprogrammed software module, including one containing a self-diagnostic utility program that now comes standard.

A very noticeable change is the series of cutouts in the upper body. Covered by removable plastic caps, these cutouts accommodate hardware attachments, which RB5X owners either construct themselves or purchase from RB5X dealers. The robot now comes standard with a speaker grille for added voice. New RB5Xs also contain an automatic battery shutoff circuit that protects the robot's batteries from draining beyond the point of damage. Owners can check the battery charge level by reading the new LED bar on the interface panel.



The upgraded RB5X is available for $1795. Upgrade kits for existing units are available for $300. For more information contact: Sharon D. Smith, RB Robot Corp., 18301 West 10th Ave., Suite 310, Golden, CO 80401. (303) 279-5525. Circle 47



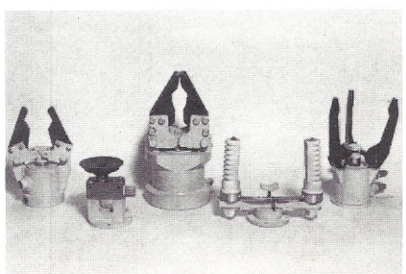
VoiceBoard Produces Synthesized Speech

The latest development in synthesized speech technology from Microvoice has resulted in natural-sounding speech that can easily be added to robotic devices. Voiceboard™ is a compact, reliable circuit board that makes it simple to incorporate speech into your product or equipment to announce warnings, messages, and instructions. As many as 64 inputs and 8 minutes of speech are available with customized speech capability. Voice is triggered through simple switch closures or by computer control. Product versions and vocabularies tailored for the robot industry allow you to add auditory features which will aid productivity and communication between man and machine. The basic OEM VoiceBoard is priced as low as $375.00 for volume purchases.

For more information contact: Microvoice Systems, 23362 Peralta Dr., Suite 5, Laguna Hills, CA 92653. (714) 859-1091.
Circle 49

Robot Grippers

Air Technical Industries has introduced a line of robot grippers and attachments including a three-finger gripper, a human-finger-like "soft touch" gripper, Venturi suction cups, and two-finger grippers. The standard off-the-shelf grippers can be mounted on any type of robot wrist. The fingers are replaceable with a variety of different fingers. All grippers are pneumatic or vacuum operated. They are also available in electromagnetic solenoid or hydraulic models for heavier capacities. Contact: Air



Technical Industries, 7501 Clover Avenue, Mentor, OH 44060. Phone: (216) 951-5191. Circle 48

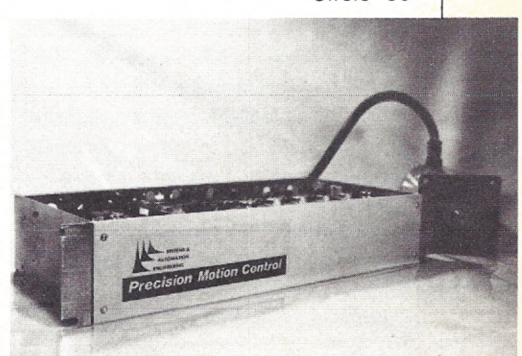
Precision Motion Control

The HB Series Pulse Width Modulated Amplifier from Systems and Automation Engineering is designed to drive DC motors in applications requiring quick response and high-quality velocity regulation, such as robotics, numerical control, semiconductor manufacturing equipment, medical equipment, and process control.

The PWM Amplifier uses an H-Bridge arrangement to provide the servo system designer with full bipolar control of both speed and acceleration while eliminating the nonlinearities normally associated with bipolar amplifiers. A high switching frequency (20kHz) is used to eliminate motor resonance problems usually found in lower frequency amplifiers. The PWM Amplifiers are available in eight models with voltages ranging from 24VDC to 90VDC, with output current to 16 Amperes.

For more information contact: Jim Mack or Alan Rutherford at Systems and Automation Engineering, 1485 Kerley Drive, San Jose, CA 95112. (408) 287-0300.

Circle 50



New Products

Robot Pets

Ropet™ is a personal robot which does not require an external computer for operation. Its built-in computer controls mobility and provides collision avoidance, the ability to obey spoken commands, and both speech and complex sound generation. Use of the industry standard Z80 processor, standard S-100 bus, and modular construction, allow easy expansion and customization. Ropet is powered by two gel cells which permit operations for up to eight hours and can be recharged overnight. Plug-in cartridges provide programs for security, entertainment, and education. External communications are available for connecting Ropet to a development station.

For more information contact: Personal Robotics Corporation, 469 Waskow Drive, San Jose, CA 95123. (408) 281-7648.

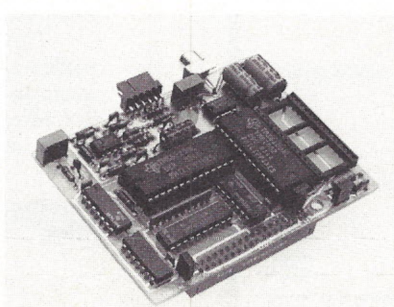
Circle 51

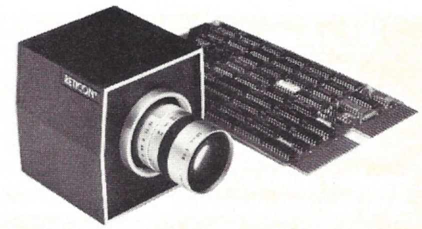
General Digital Speech Synthesizer

The GDX-SPEECH-TI speech synthesizer is based on a dedicated TI-5220 speech processor and uses linear predictive coding techniques. The module generates a natural-sounding voice using a standard, onboard 206-word industrial vocabulary. An unlimited vocabulary is available using LPC-10 data supplied by an external processor. The module is self-contained and includes an onboard LPF, 2 W audio amplifier, phono jack, and volume control. The user simply connects an 8 ohm speaker. In addition, the module allows mixed low-level audio from an external source and synthesized speech to be overlaid. A manual included with each module provides software driver routines.

Price for the module is $285.00. Quantity discounts are available. For further information contact: Leigh Standish, 7 Linden Place, Hartford, CT 06106. (203) 527-3845.

Circle 53





Reticon to Q-Bus Interface

EG&G Reticon has announced a camera plus computer interface board combination designed for the Digital Equipment Corporation Q-Bus. The Model RSB6320 is designed to accept digital 1-bit binary images from virtually all Reticon Line Scan and Area Image Sensing cameras. Image data can be processed into a run-length encoded format without the need for computer intervention. Two encoding modes can be selected. One mode stores the pixel address of an image transition, the other mode stores the transition data as pixel groups between transitions. Run-length encoded data is stored on-board in a 253 word memory. The interface board is priced at $895. Contact: EG&G Reticon, 345 Potrero Avenue, Sunnyvale, CA 94086-9930. (408) 738-4266.

Circle 52

Classified Advertising

ROBOTICS INDIVIDUAL with background to design, develop and implement a Robotics curriculum for Technical Training Institute. Must be hard-working, imaginative and a self-starter. Excellent opportunity for the right person. Send resume to: TCI ELECTRONICS DEPT., 605 Day Hill Road, Windsor, CT 06095.

ROBOT AND ROBOT PERIPHERAL MAKERS to team up with marketing organization for JOINT VENTURE. Contact: Personal Robots, Inc., 1000 North Ave., Waukegan, IL 60085.

CUSTOM SYSTEMS INTEGRATION—CP/M, MP/M, CP/M-86, UNIX, S-100, IBM-PC, M68000 Add-ons for Heath Robot—Request Catalog. Interface Technology, Box 745, College Park, MD 20740. (301) 490-3608.

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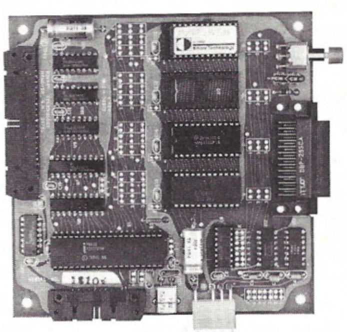
SIBEC 51



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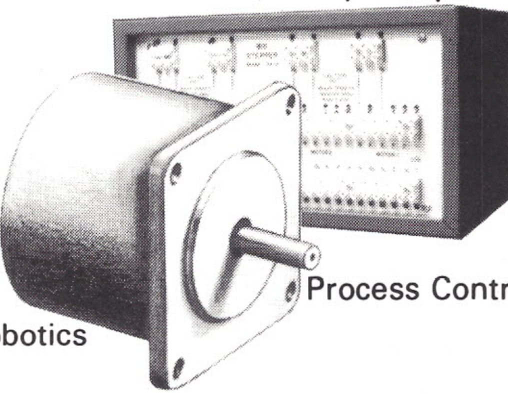

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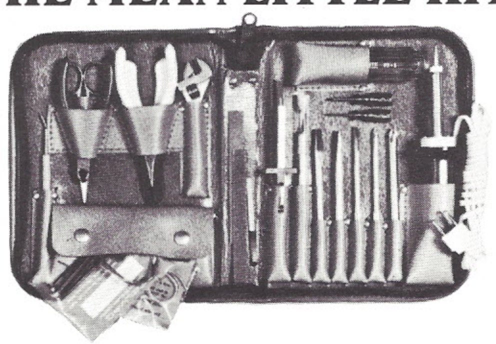

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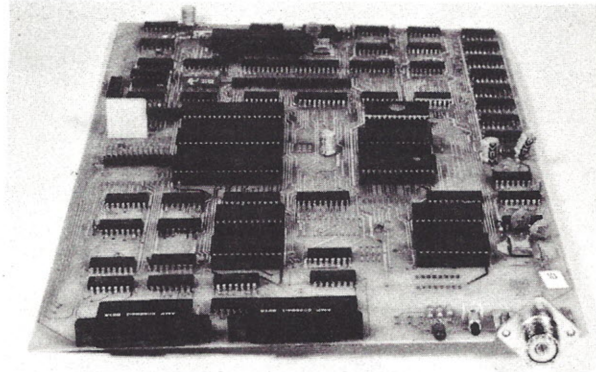

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At the end of each article in *Robotics Age* are three evaluation numbers. You rate the articles by circling the appropriate number on a Reader Service Card and returning the card to us.

The first issue to use article ratings was the September/October 1983 issue. The article receiving your highest rating is "ODEX I: The First Functionoid", by Marvin Russell, Jr. Appearing in second place is "A Cog-Wheel Driven Robot Cart" by James R. Grote, Ph.D.

I'd like to express my appreciation to Marvin and James for submitting two excellent articles.

RGAC

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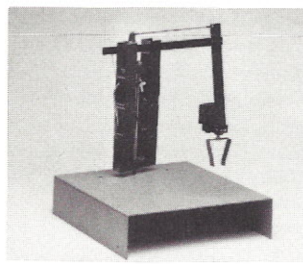

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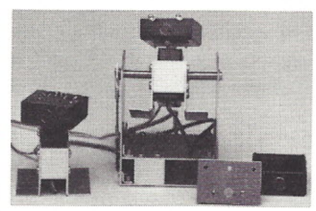

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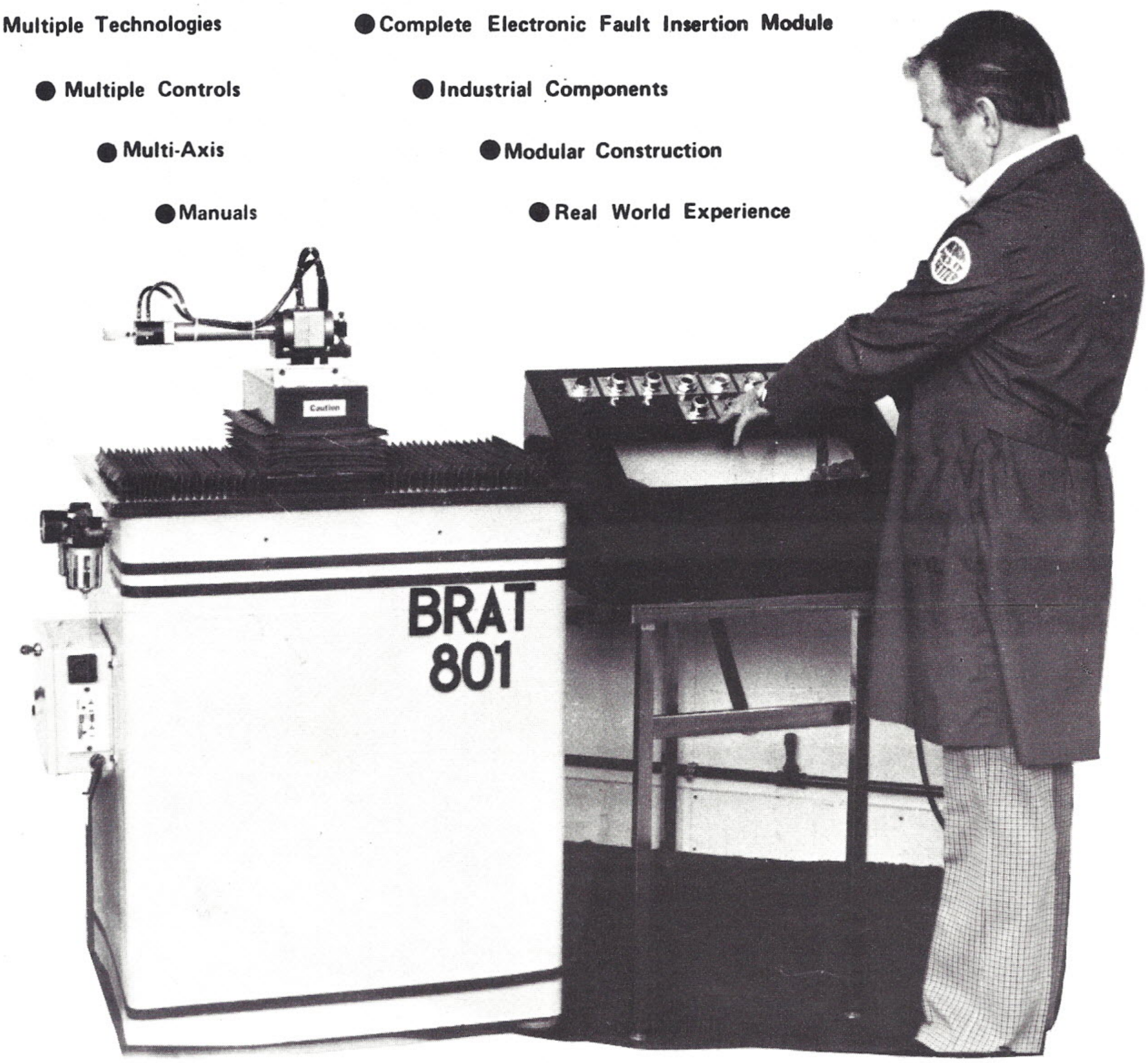

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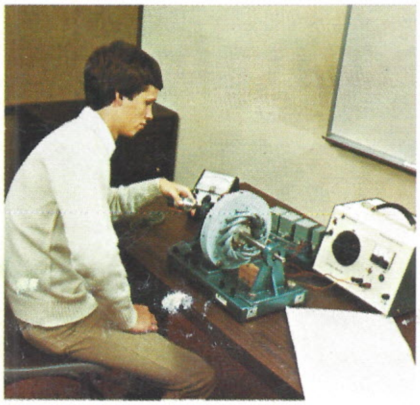

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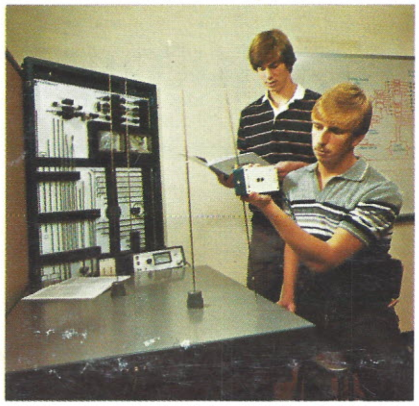

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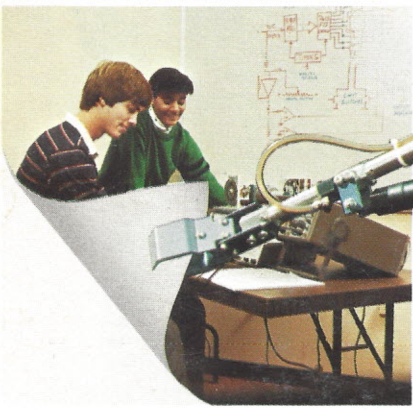

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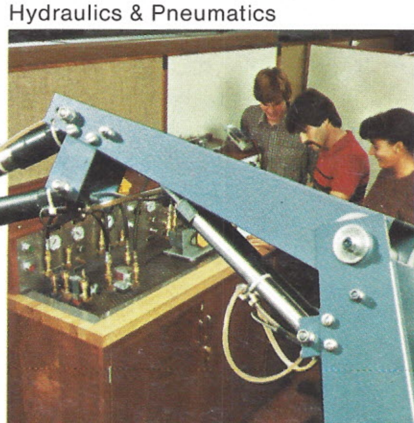

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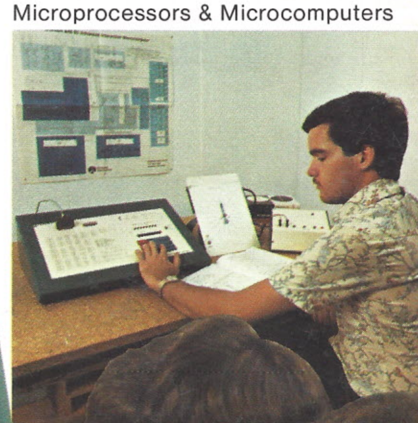

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